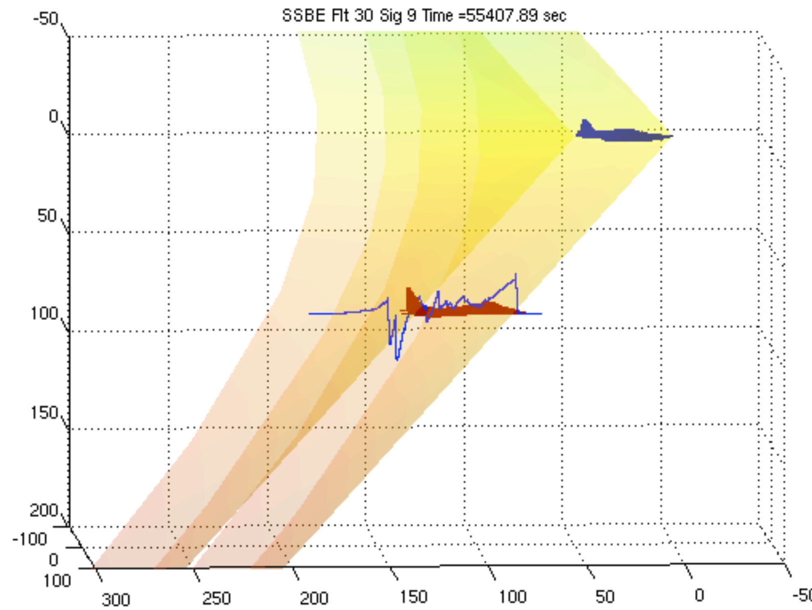
Shaped Sonic Boom Demonstration / Experiment
Airborne Data
SSBD Final Review



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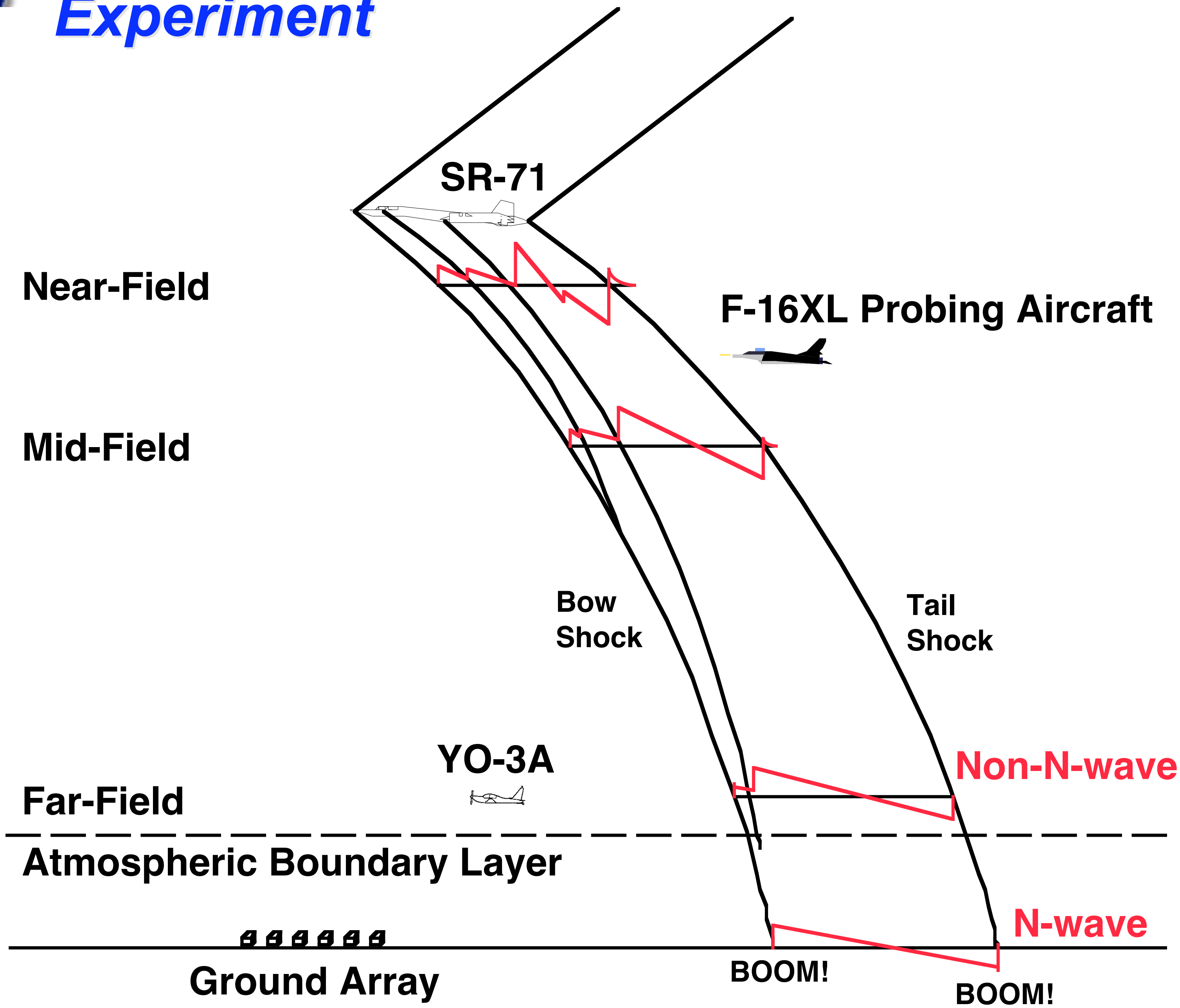
Edwards, California
August 17, 2004

Outline

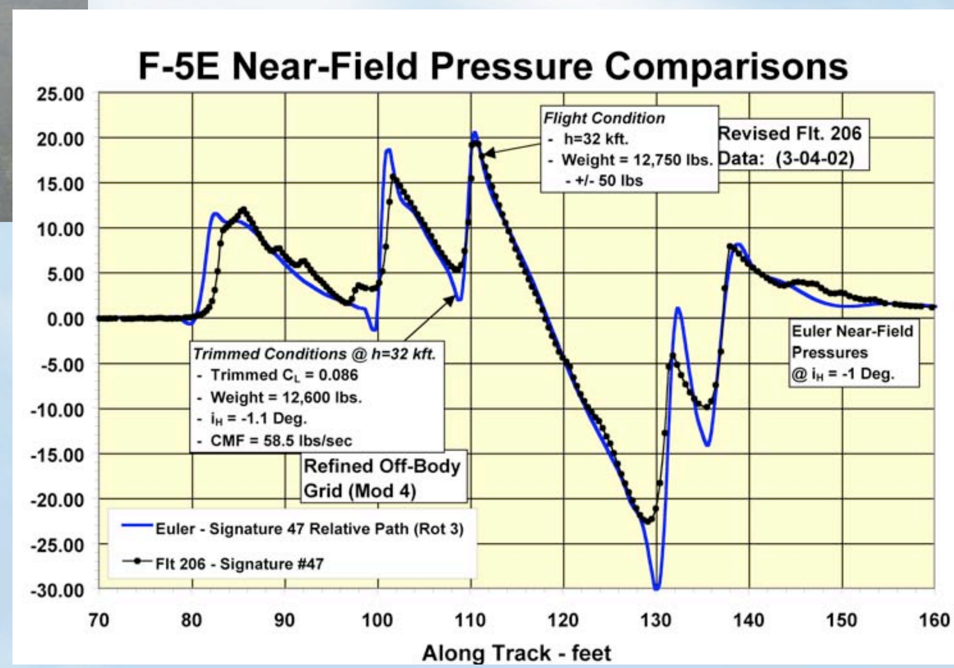
- Past airborne shock measurement efforts
  - SR-71 Sonic Boom Propagation Experiment
  - F-5E Inlet Spillage Shock Measurement
- Flight test approach
- GPS data
- SSBD Mach calibration
- Super Blanik L-23 sailplane
- Near-field probing
  - Maneuvers
  - Control Room Displays
  - Pressure Instrumentation
  - Signatures
- Summary
- CFD comparison to flight data, Keith Meredith, Northrop-Grumman Corp.

SR-71 Sonic Boom Propagation Experiment



Inlet Spillage Shock Measurement - Feb. '02

DFRC Facilities and Expertise used to Accurately Record Inlet Shock Strength in Flight…



… Resulting in Modification to Design Process

Airborne Data Flight Test Approach

F-5E Shaped Sonic Boom Experiment

- NASA Dryden F-15B probes below and to side of F-5E, 60 to 720 ft flightpath separation, F-15B nose always behind SSBD tail for supersonic probing
- F-15B noseboom pressures measures shock strengths
- GPS on both aircraft measures relative position
- GPS basestation (Palmdale & Edwards) for postflight carrier-phase differential corrections
- USAF TPS Super Blanik L-23 flies at 6,000 to 8,000 ft over North Base ground array, records sonic boom on wingtip microphone, GPS also

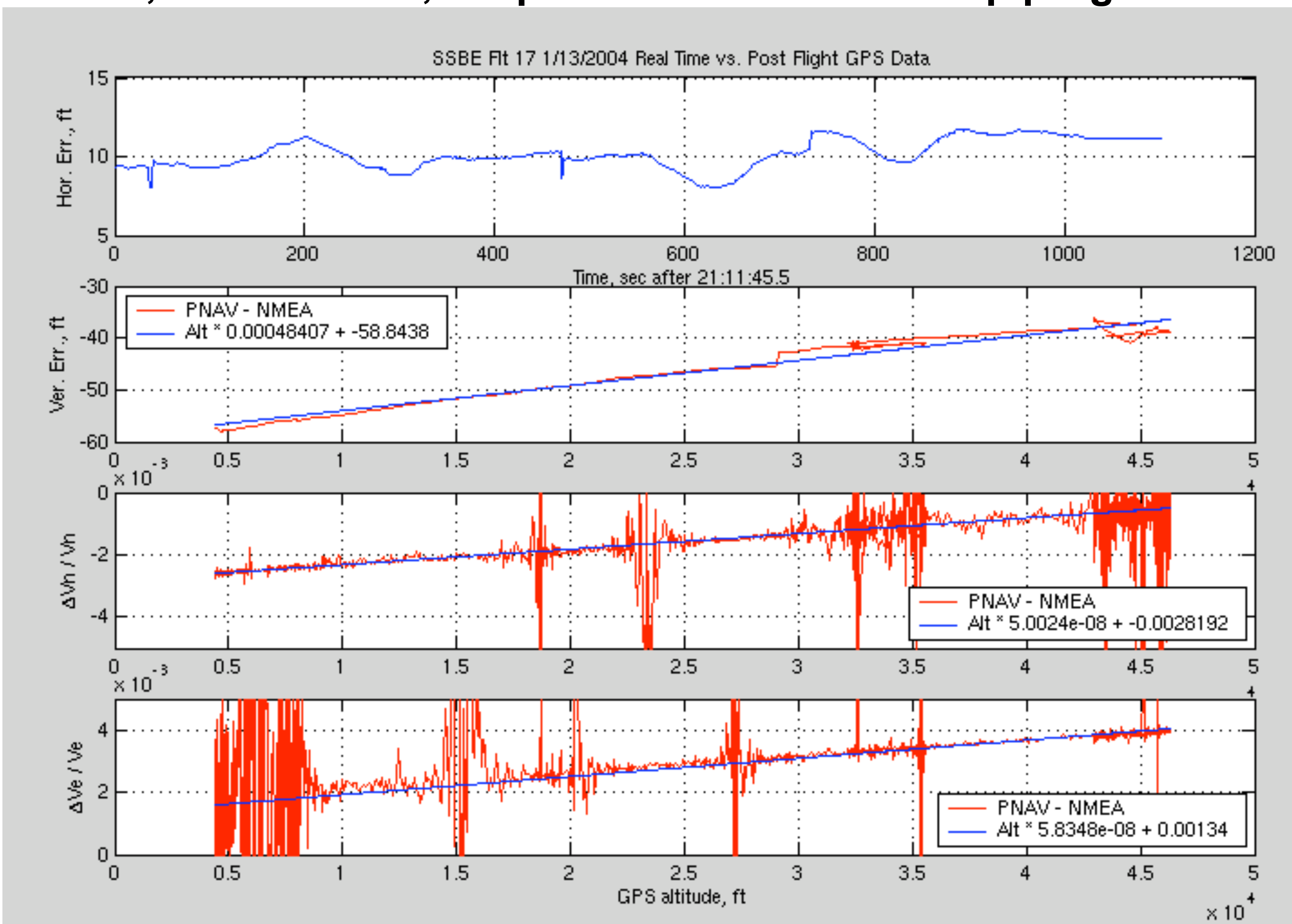
GPS Data Processing

- SSBD, F-5E, F-15B, and L-23 all had carrier-phase differential GPS
- GPS basestations at Palmdale and NASA Dryden
- Ashtech's PNAV program used for post-flight time-based position, velocity for each aircraft
- Integer ambiguity resolution set to "float" as GPS satellite lock lost at times during flight, "fixed" used for some probing flights
- Raw GPS data lost on six flights, suspect incorrect downloading program used
- Realtime GPS data (NMEA messages) received from SSBD and baseline F-5E on most flights on field-deployed laptop computer. Was able to calibrate NMEA to PNAV differences and recover four flights
- GPS data lost
  - Flt 14 supersonic pass
  - Flt 15 entire flight

GPS Realtime vs. Postflight Data

F-5E Shaped Sonic Boom Experiment

- Lateral shift small, ignored, raw GPS data not lost for probing flights
- Altitude shift of NMEA due to realtime ionospheric modeling off
- Relative error of velocity components as a linear function of altitude on SSBD and baseline F-5E, not on F-15B, suspect incorrect GPS setup program



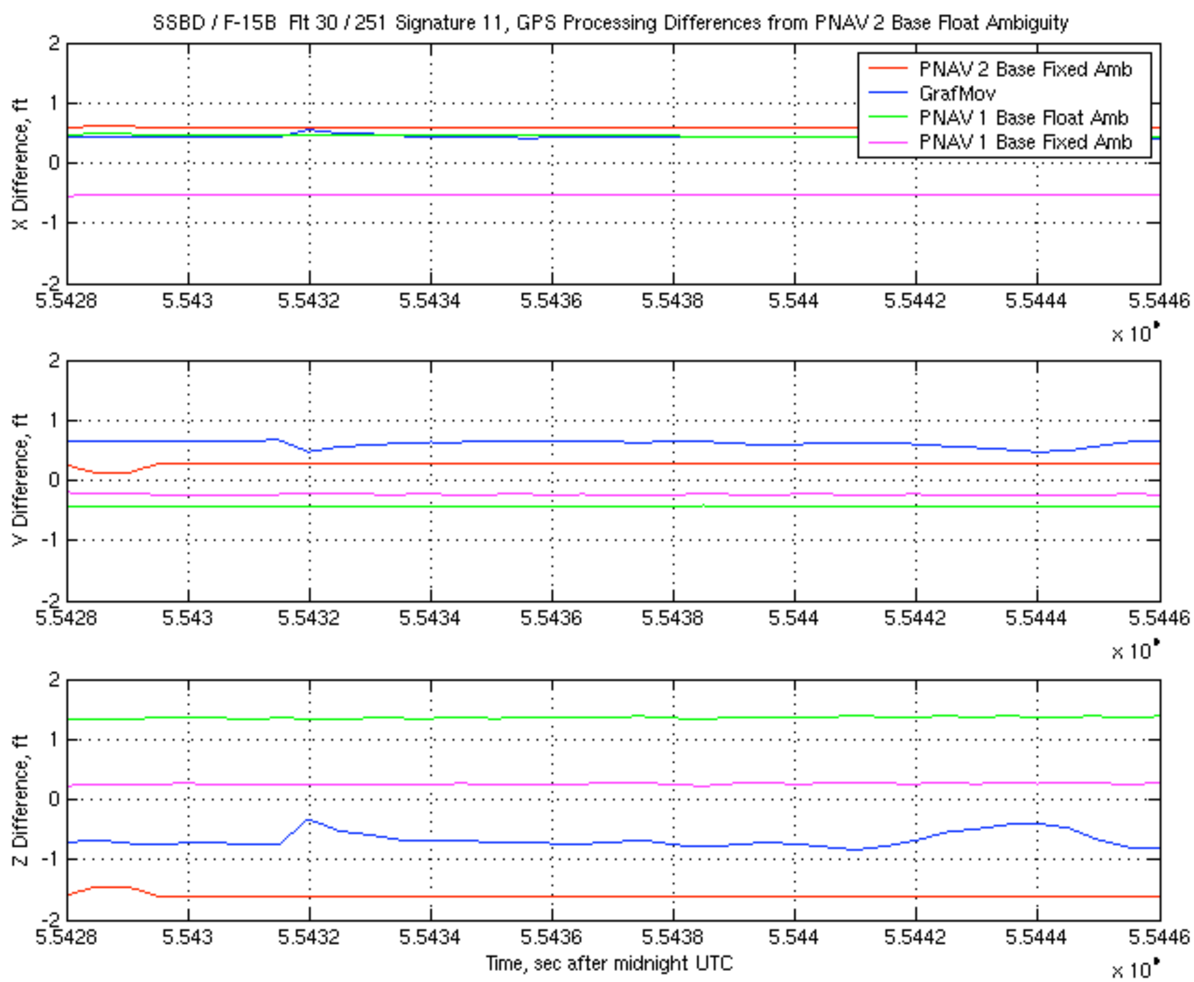
GPS Relative Position

- Position data from GPS antennae translated to SSBD nose (w/o noseboom) as origin, F-15B pressure ports based on:
  - 0° roll angle
  - GPS flight path angle plus assumed AOA for pitch angle
  - 1° AOA for F-15B, 1.75° AOA for SSBD (neither aircraft had test AOA sensor)
  - GPS flight path heading of each vehicle (F-15B Euler angles not instrumented, SSBD Euler angles not believable)
- Translated latitude, longitude, altitude differenced to give North, East, Down separation components
- Relative position components rotated to SSBD stability axes using GPS velocity and atmospheric reference lateral winds to give airmass relative positions.
- Carrier-phase differential GPS solutions investigated:
  - PNAV “Float” (baseline) and “fixed” (best for now) ambiguities with Palmdale basestation for SSBD
  - PNAV “Float” and “fixed” ambiguities with Edwards basestation for SSBD
  - GrafMov software (gives carrier-phase relative position without basestations)
- All solutions within +/- 2 ft of baseline in each component
- NASA’s Autonomous Aerial Refueling project gives optical relative position good to inches to determine best GPS processing

GPS Relative Position Differences

F-5E Shaped Sonic Boom Experiment

- Little to no variation during signature
- Other signatures give different biases



Mach Calibration Method

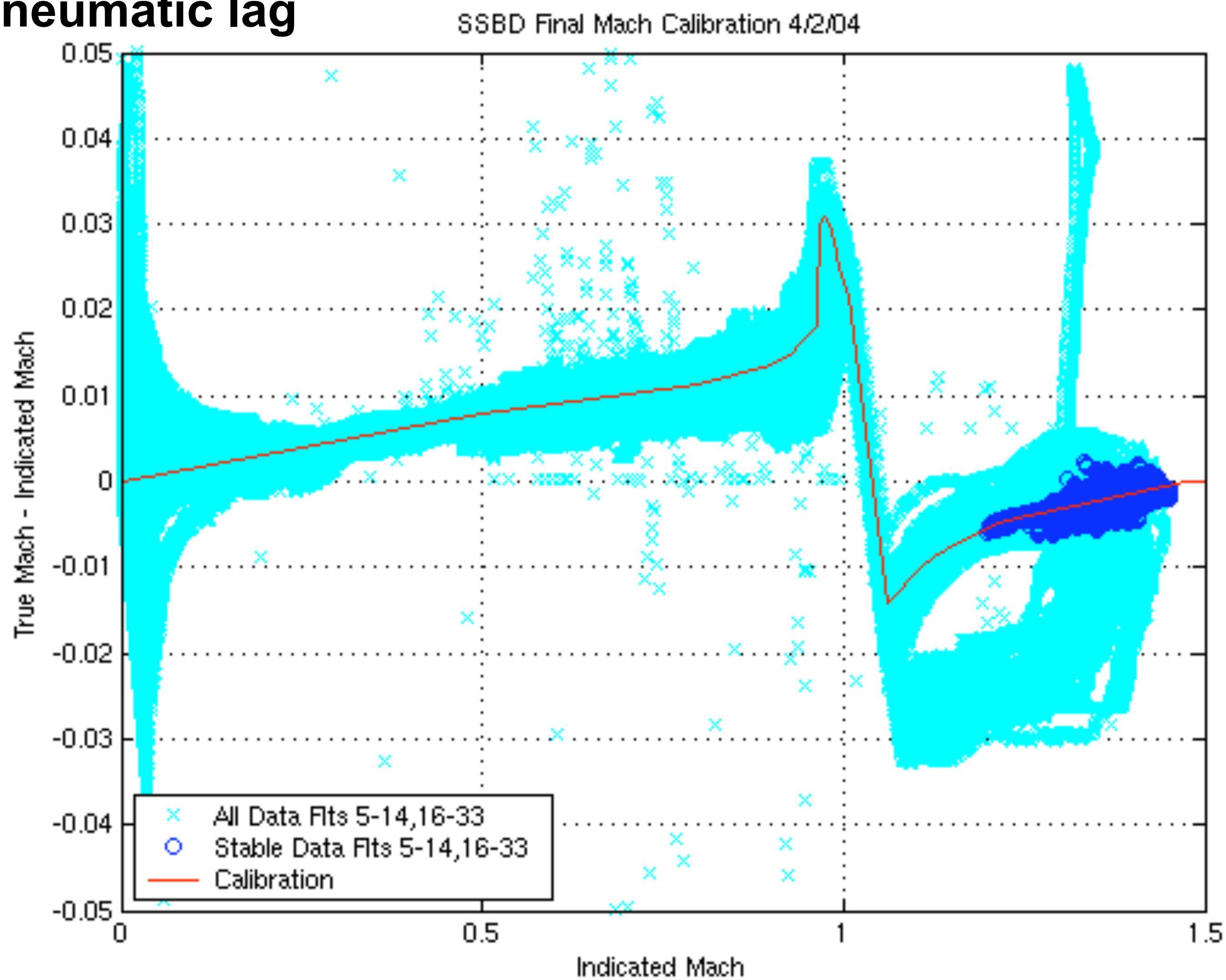
F-5E Shaped Sonic Boom Experiment

- Assume zero error in total pressure
- Indicated Mach, M_i, is a function of indicated total and static pressure only
- GPS data and geodetic separation model gives geometric altitude above mean sea level, Z
- GPSsonde and atmospheric analysis gives pressure altitude, Hp, and lateral pressure gradient as a function of Z
- Some GPSsonde data were off in excess of 300 ft
  - DC shifts in altitude after data dropouts
  - Some late balloon launches did not have proper initial pressure set
  - Sometimes balloon package is just “bad”
- Combine GPS derived Z with atmospheric Z-Hp to give true Hp for all aircraft data points
- Aircraft total pressure with true Hp gives true Mach, M_{inf}
- Mach correction, $M_{inf} - M_i = f(M_i)$ during stable flight
- Stable Data: GPS $|V_d|<10$ fps, $|\phi|<10°$, GPS error < 10 ft

Mach Calibration

F-5E Shaped Sonic Boom Experiment

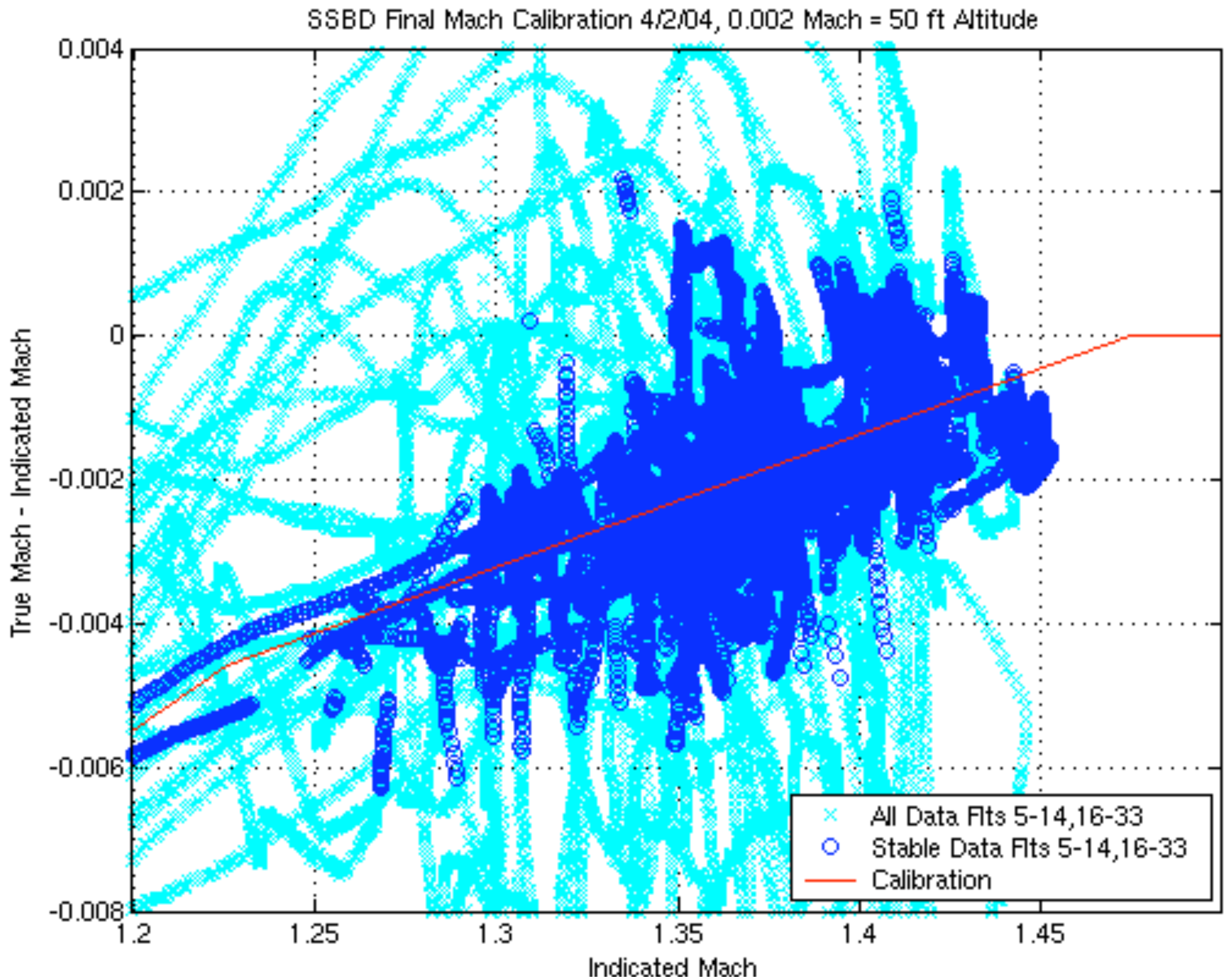
- **Large hysteresis loop during climbs and descents due to pneumatic lag**



Mach Calibration, Stable Supersonic

F-5E Shaped Sonic Boom Experiment

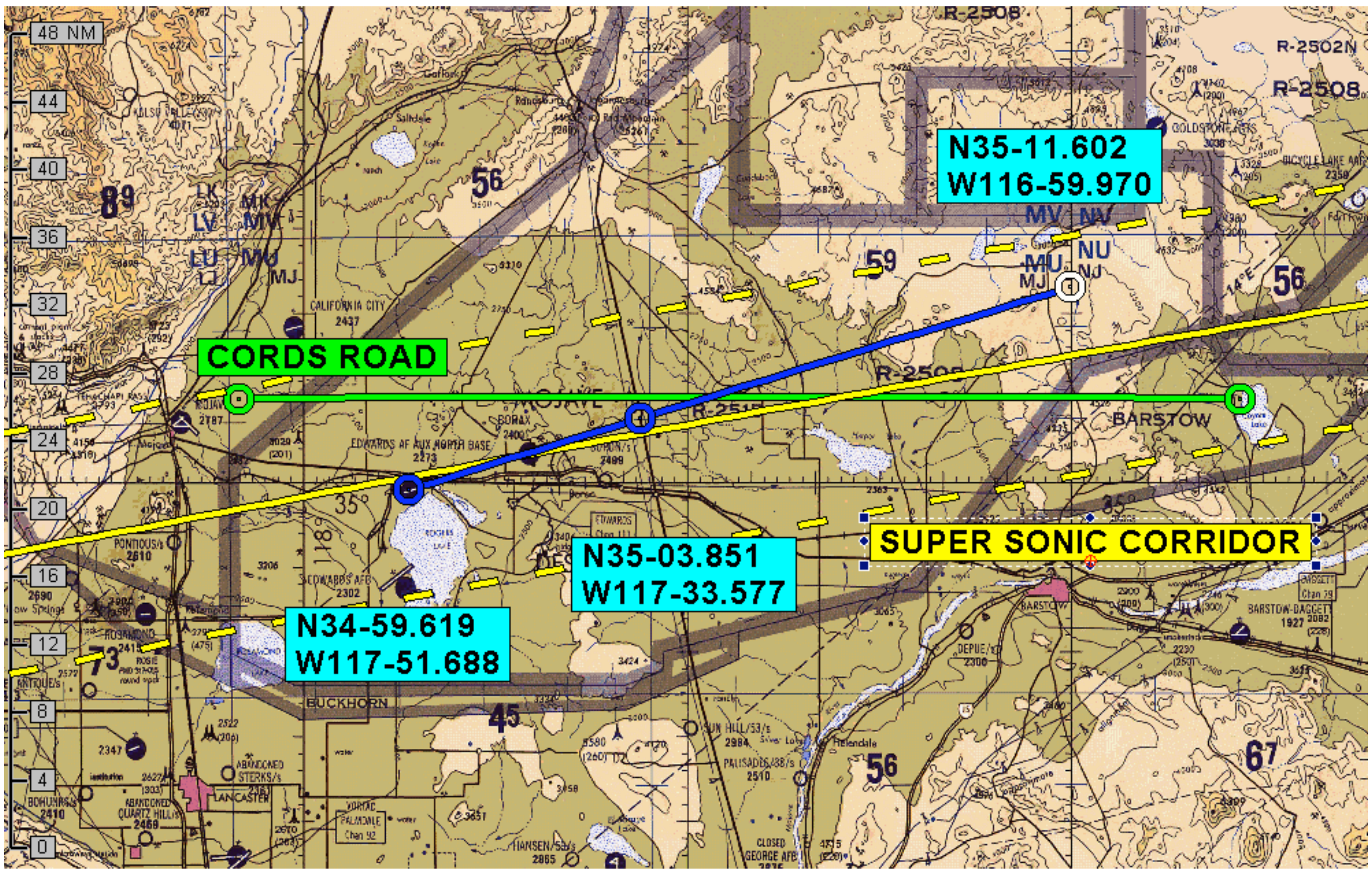
- 1-σ Mach error 0.00084 or 20 ft altitude error
- GPSsonde error of 300 ft would cause 0.013 Mach error



Flight Region

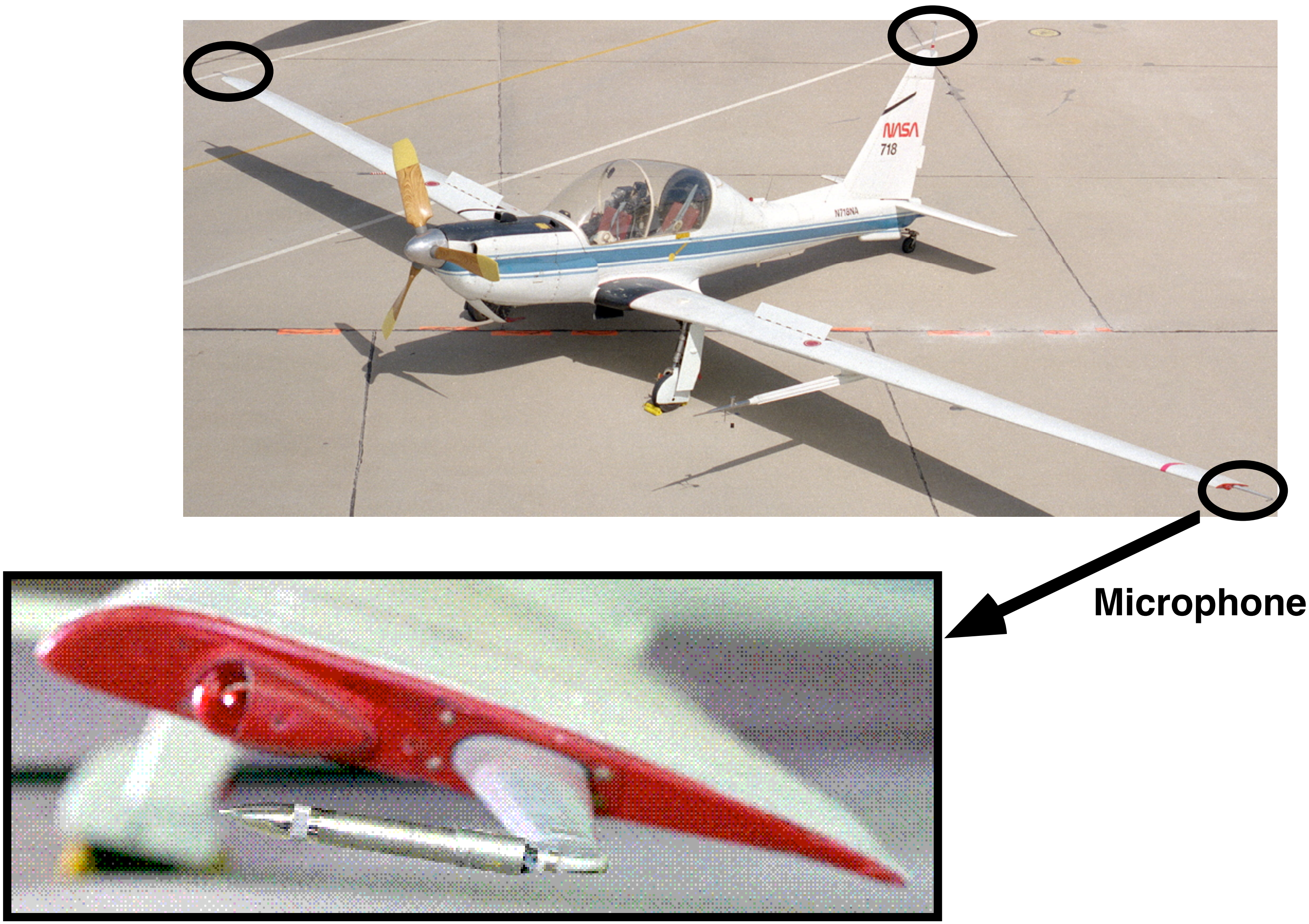
F-5E Shaped Sonic Boom Experiment

- F-15B probing at SSBD stable points, Hwy 395 to North Base, and reverse track
- Sailplane over ground array



YO-3A Instrumentation

- Microphones on wingtips and vertical tail
- Microphones, airdata, time, and voice on FM recorder
- Handheld GPS for position fix when boomed



USAF TPS Super Blanik L-23 Sailplane

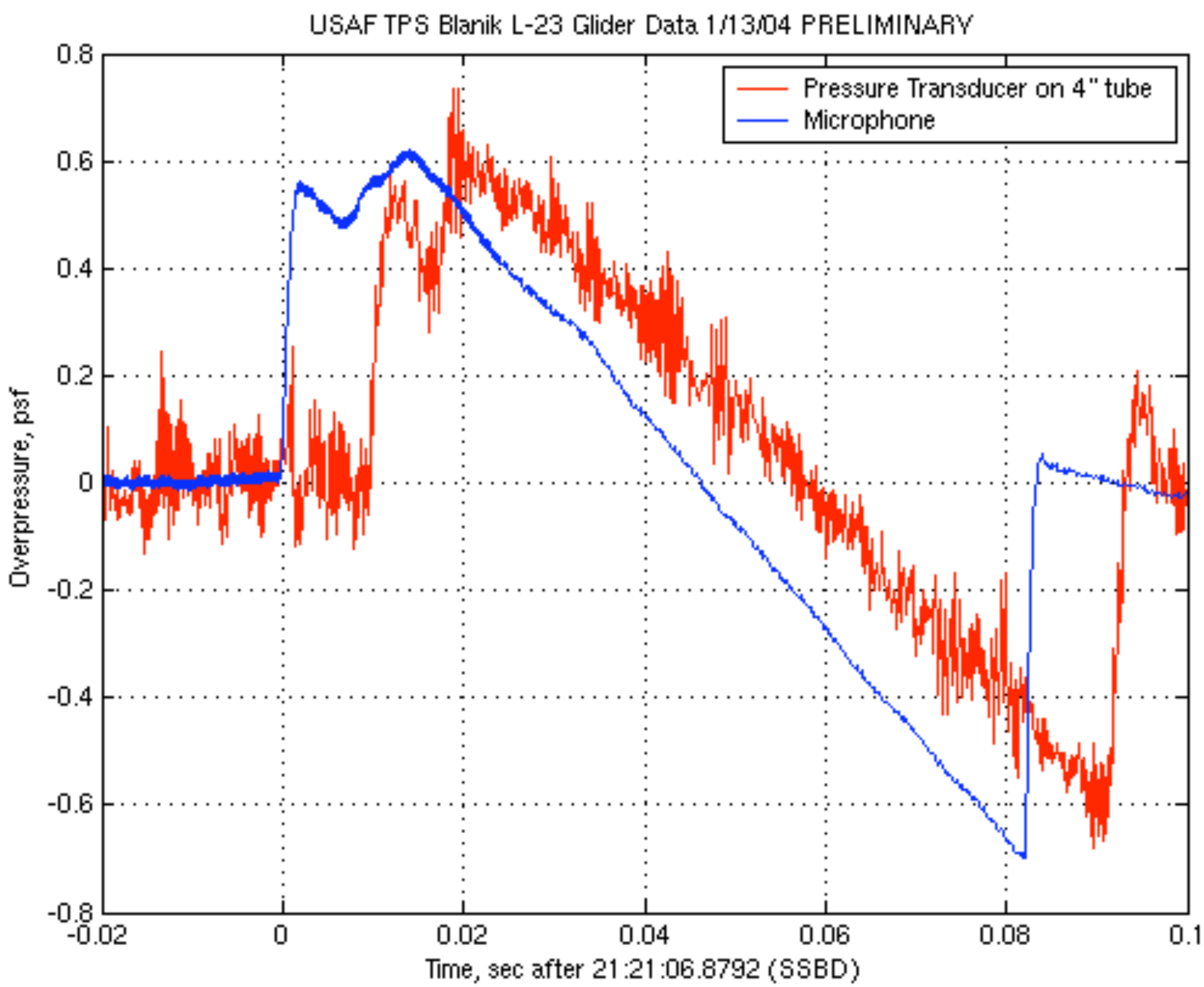
- Sailplane with sonic boom microphone on wingtip at 6,000 to 8,000 ft over ground array
- Same boom recording design philosophy of YO-3A, with better microphone, recorder
- USAF TPS under contract to NASA Dryden for effort, TPS has all aircraft operation and safety of flight

L-23 Sonic Boom Instrumentation

F-5E Shaped Sonic Boom Experiment

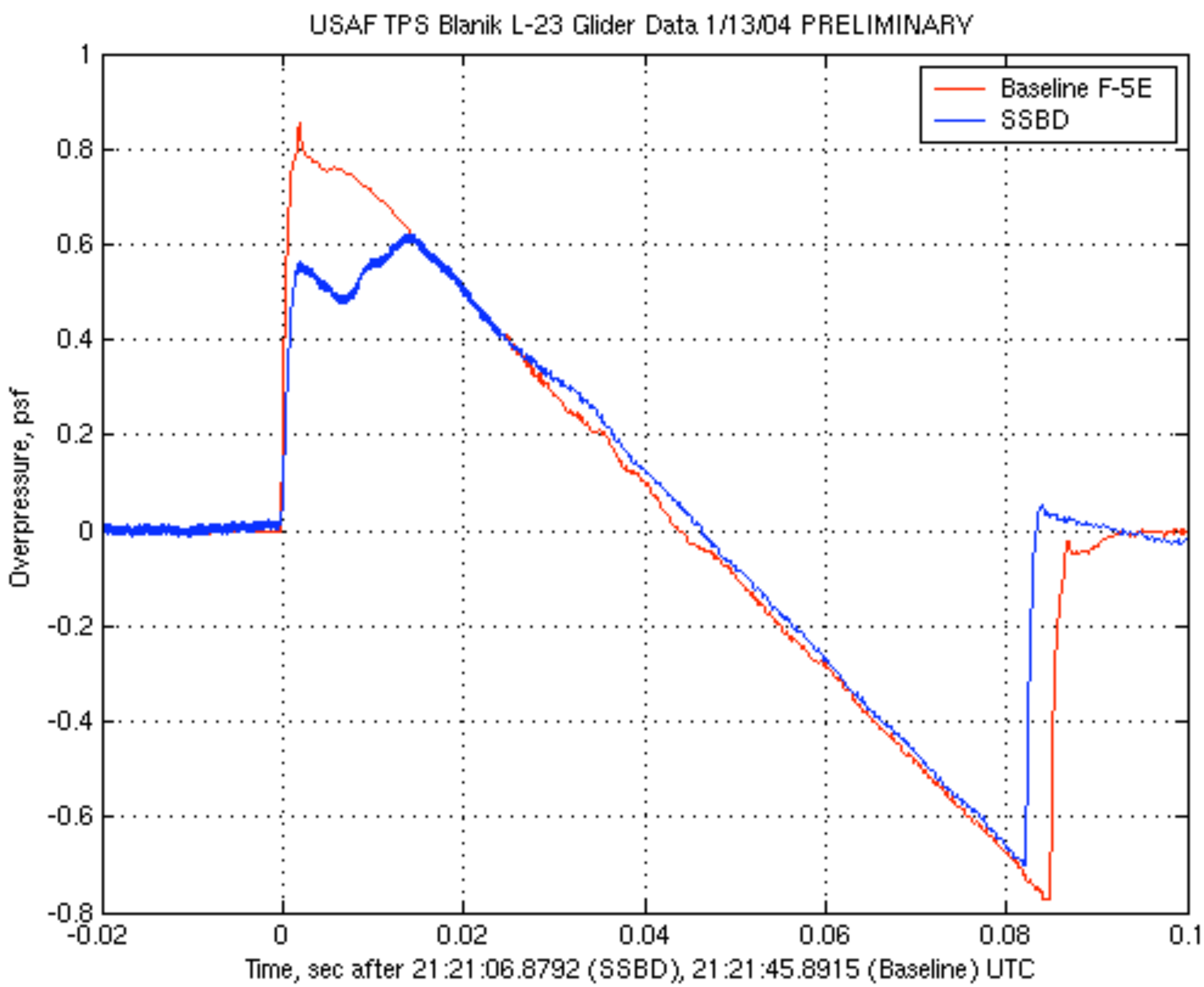
L-23 Pressure & Microphone Data

F-5E Shaped Sonic Boom Experiment



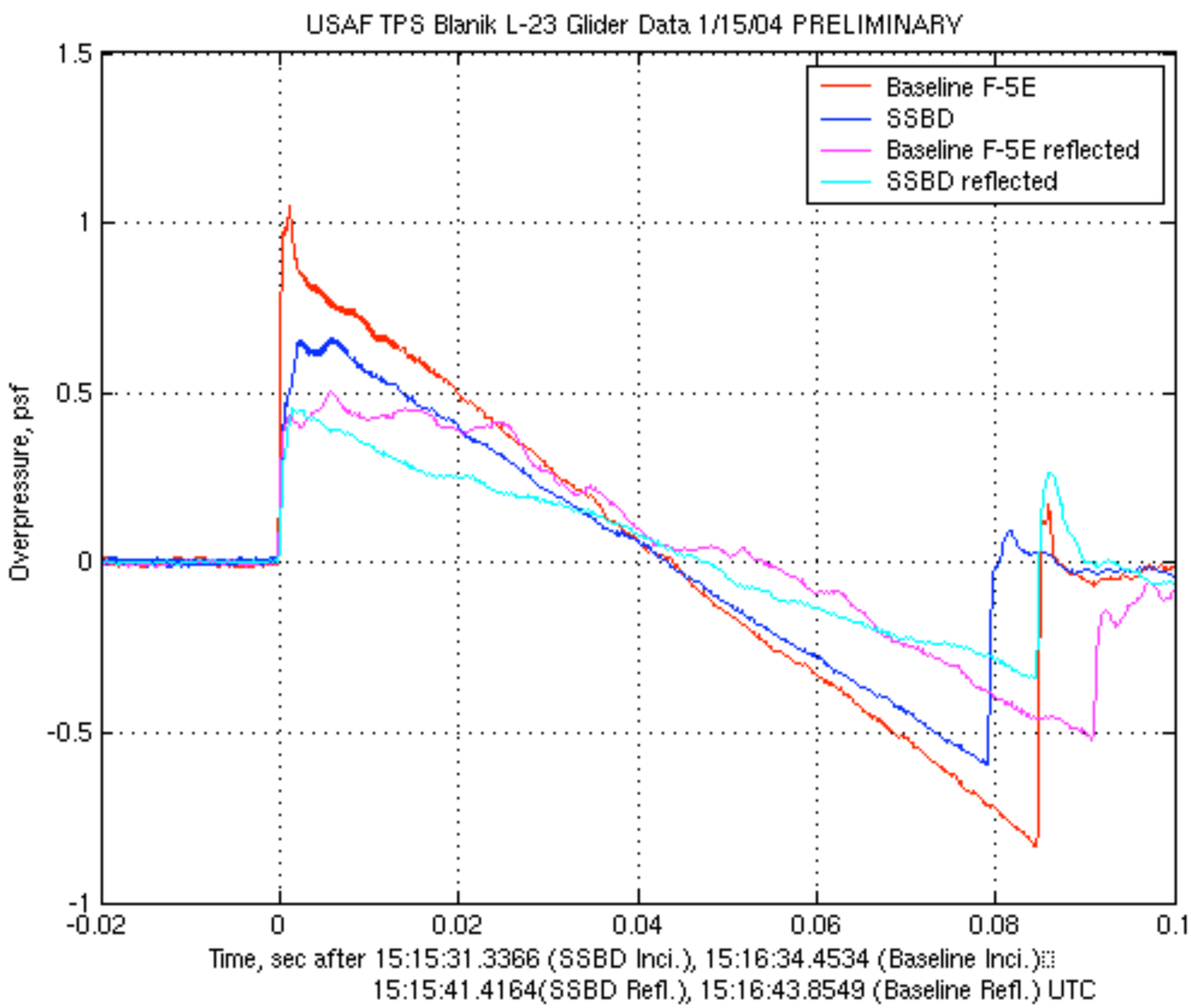
SSBD & Baseline Booms on Glider

F-5E Shaped Sonic Boom Experiment



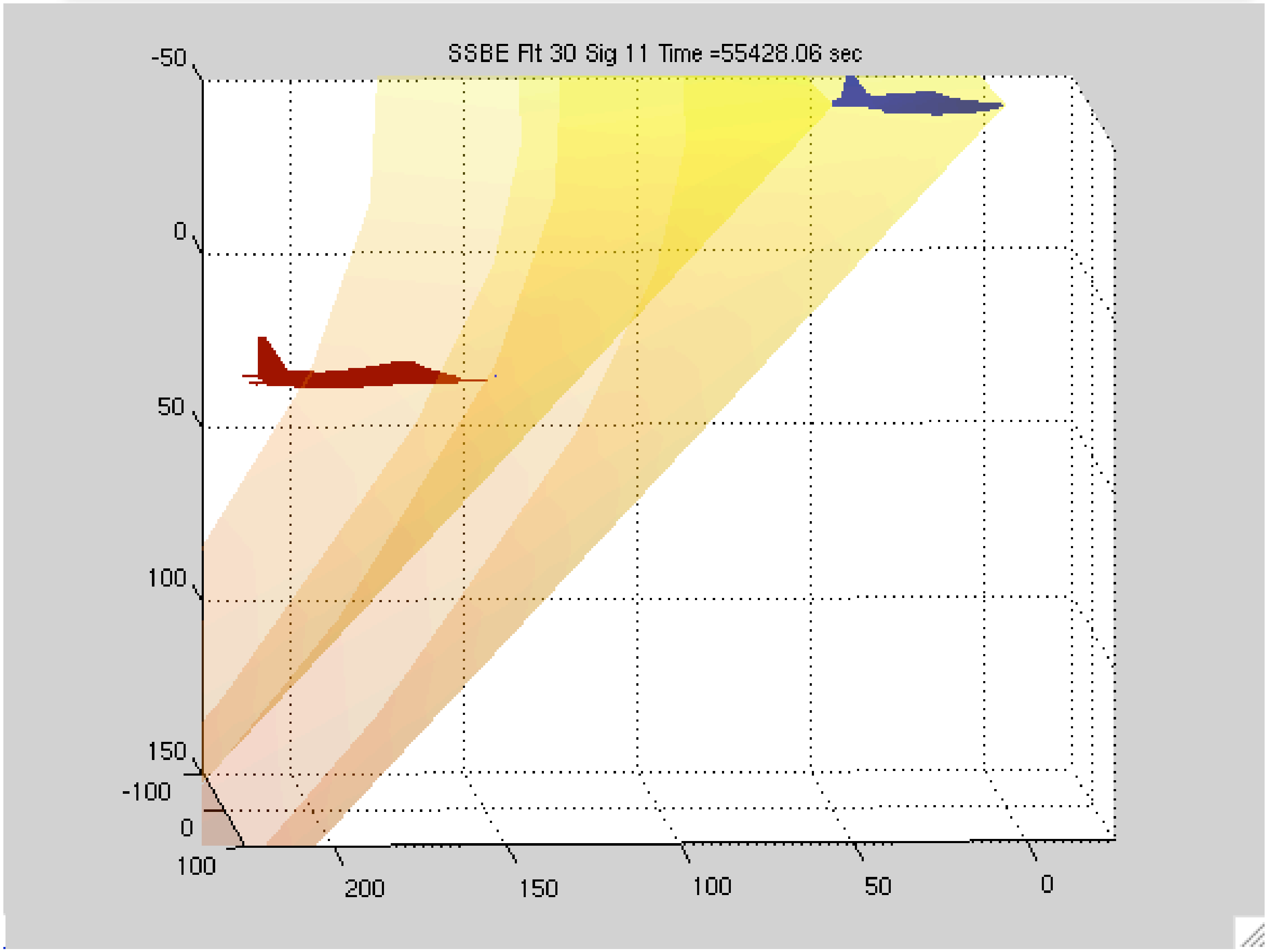
Incident and Reflected Booms

F-5E Shaped Sonic Boom Experiment



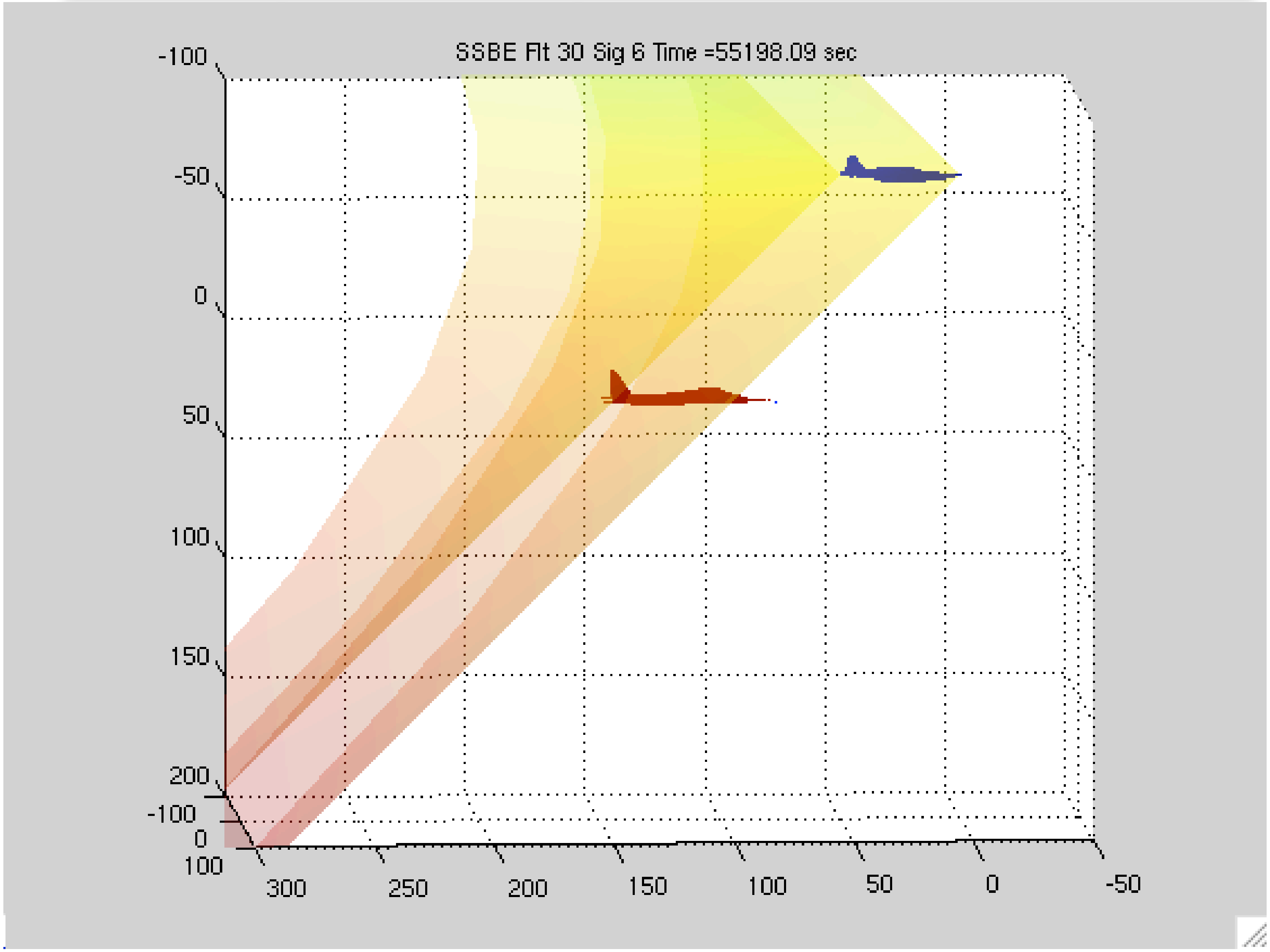
Shock Probing Back to Front

F-5E Shaped Sonic Boom Experiment



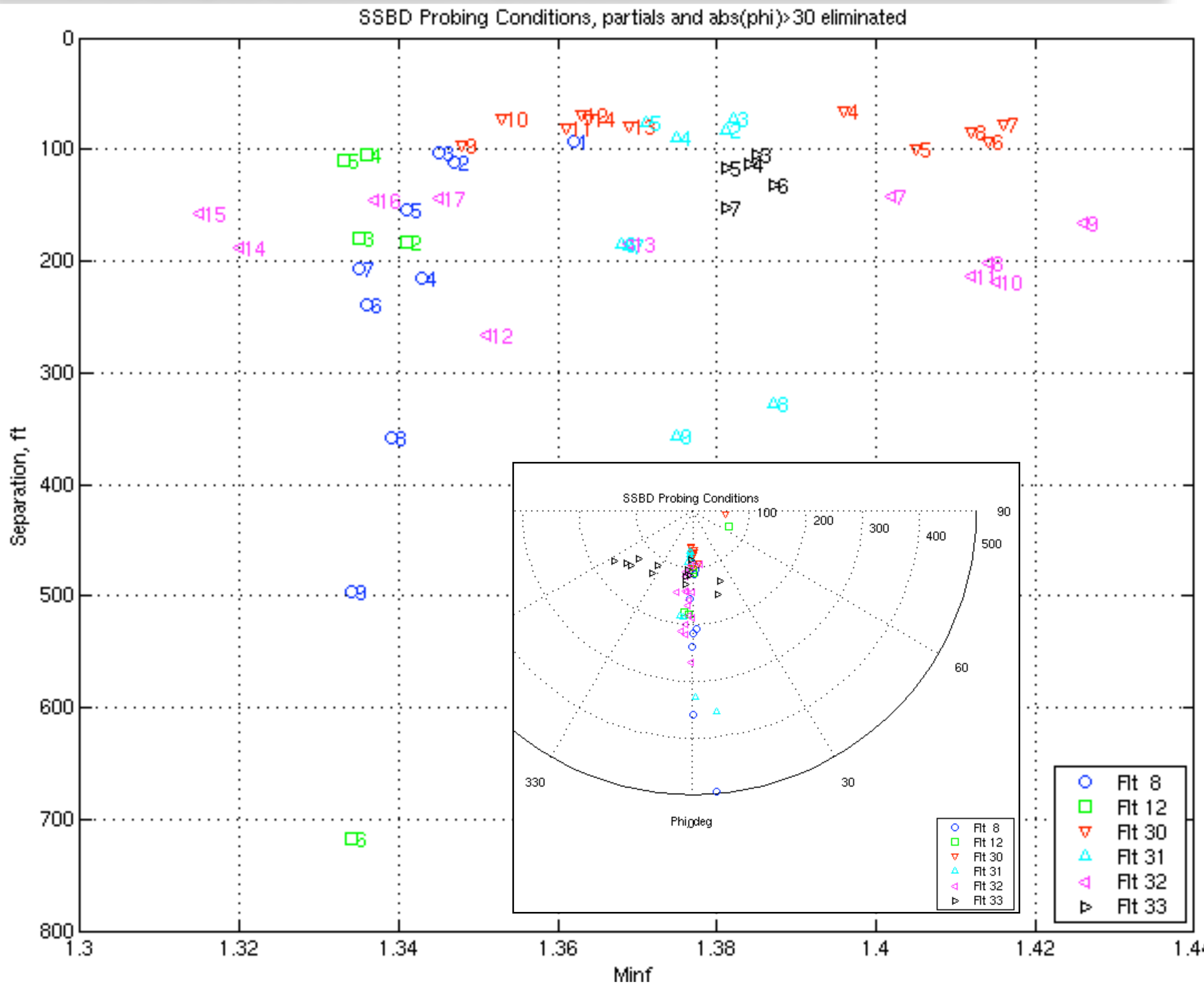
Shock Probing Front to Back

F-5E Shaped Sonic Boom Experiment



Probing Separations

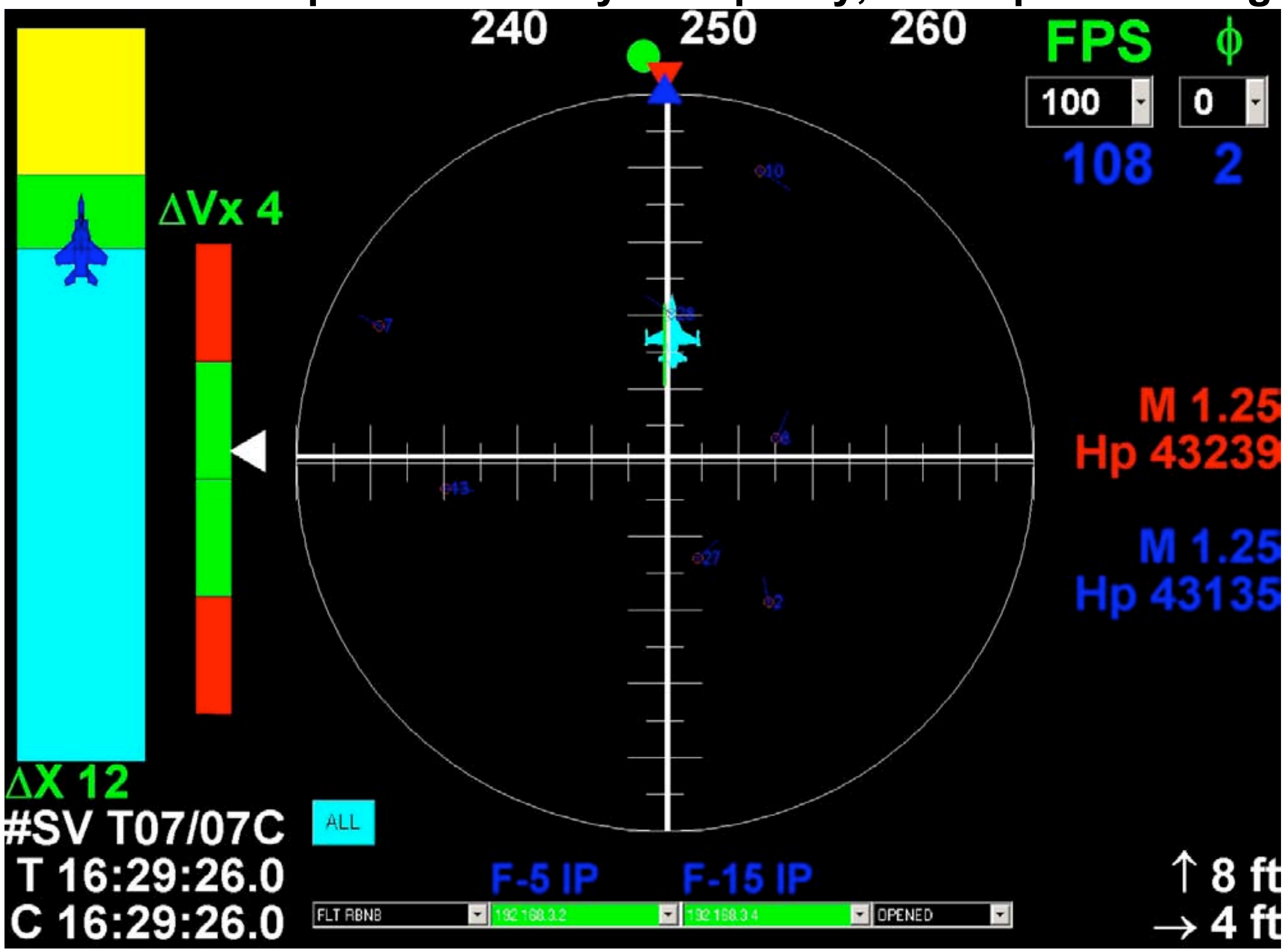
F-5E Shaped Sonic Boom Experiment



Control Room Sonic Boom Position Display

F-5E Shaped Sonic Boom Experiment

- For indication purposes, located in control room
- Mission controller can suggest fine position and rate adjustments
- Enhances test point efficiency and quality, not required for flight

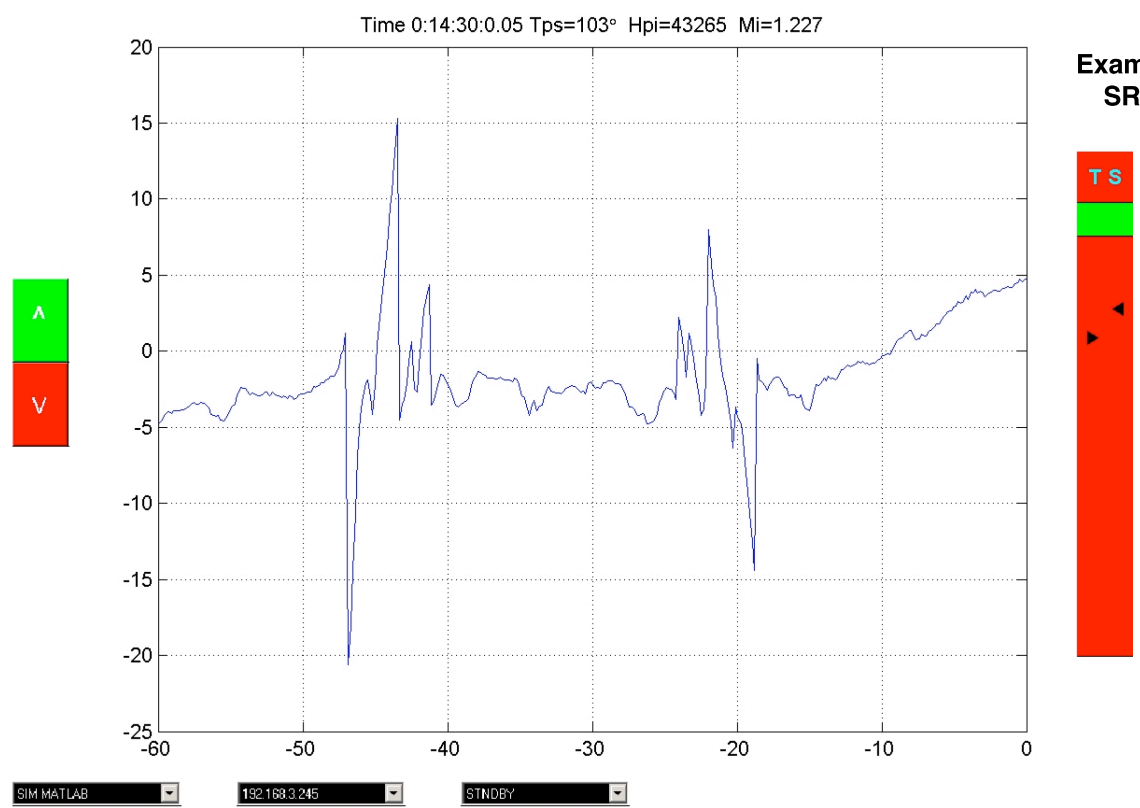


Example Data from SR-71 / F-16XL

Control Room Sonic Boom Display

F-5E Shaped Sonic Boom Experiment

- Direct indication of measured shock waves
- Mission controller can advise if ahead or behind shock waves
- Enhances test point efficiency, not required for flight



Example Data from SR-71 / F-16XL

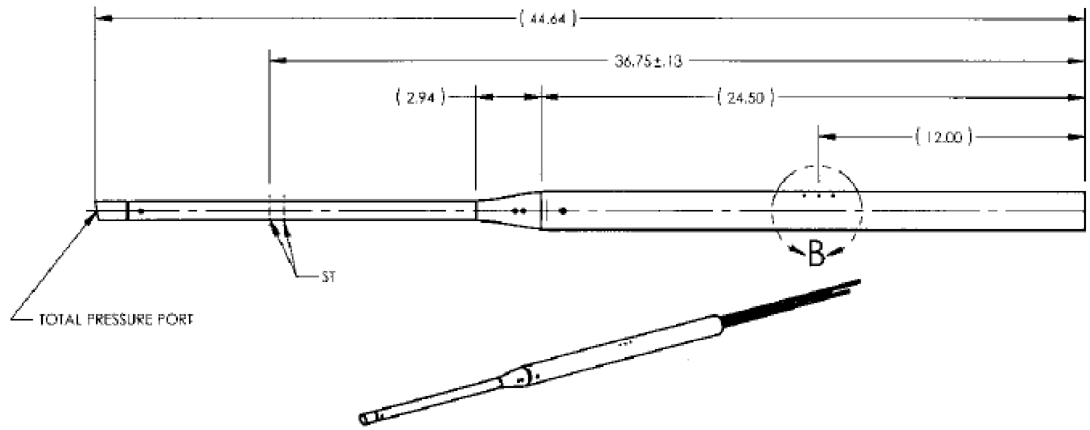
Remote Flight Monitoring

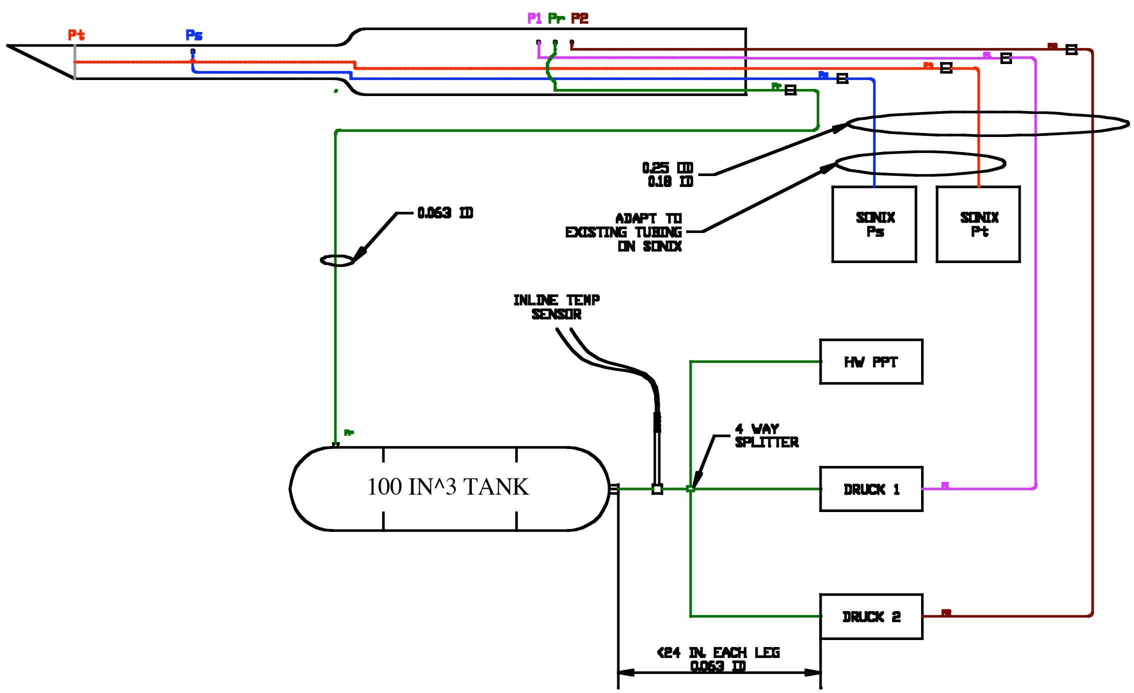
F-5E Shaped Sonic Boom Experiment

- Realtime GPS data received in field via Pacific Crest UHF radio modem
- Matlab program displays flight conditions, plots flight path on map
- Realtime data recorded, saved four flights of GPS data

Sonic Boom Probing Noseboom

F-5E Shaped Sonic Boom Experiment





F-15B Pressure Measurements

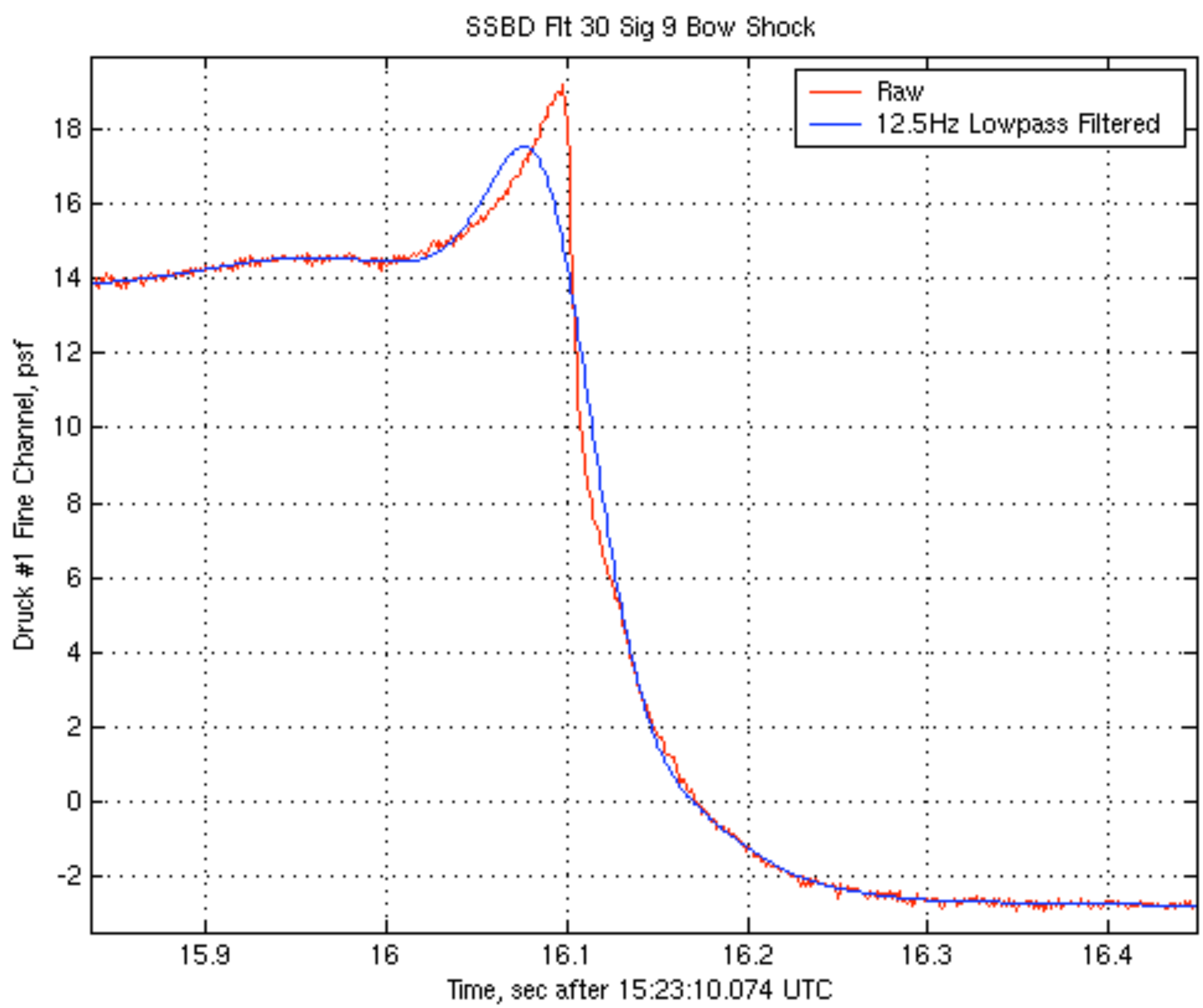
F-5E Shaped Sonic Boom Experiment

- August 2003 SSBD flights
  - 252 in^3 lag tank selected based on pneumatic simulation
  - Druck differential pressure transducer output had long run to PCM system: noisy data due to EMI
  - Dive into test point with large tank caused Drucks to be overranged for almost all probing data
  - Lag tank absolute transducer showed SSBD shock waves: inconceivable
  - 17 sps Sonix static pressure transducer on F-15B used for overpressures
- January 2004 SSBE flights
  - August 2003 flight data used to adjust pneumatic simulation, 100 in^3 tank fabricated
  - 7 grams of attic insulation used in tank to prevent “ringing”
  - Druck’s output sent to TTC multiplexer recorder
    - 1000 sps
    - shorter run
    - lower noise
  - Excellent differential pressure data
  - Absolute pressure transducer on tank showed up to 10 psf shifts when F-15B microphone keyed, easy to remove shifts
  - Lag tank absolute transducer showed no SSBD shock waves as expected

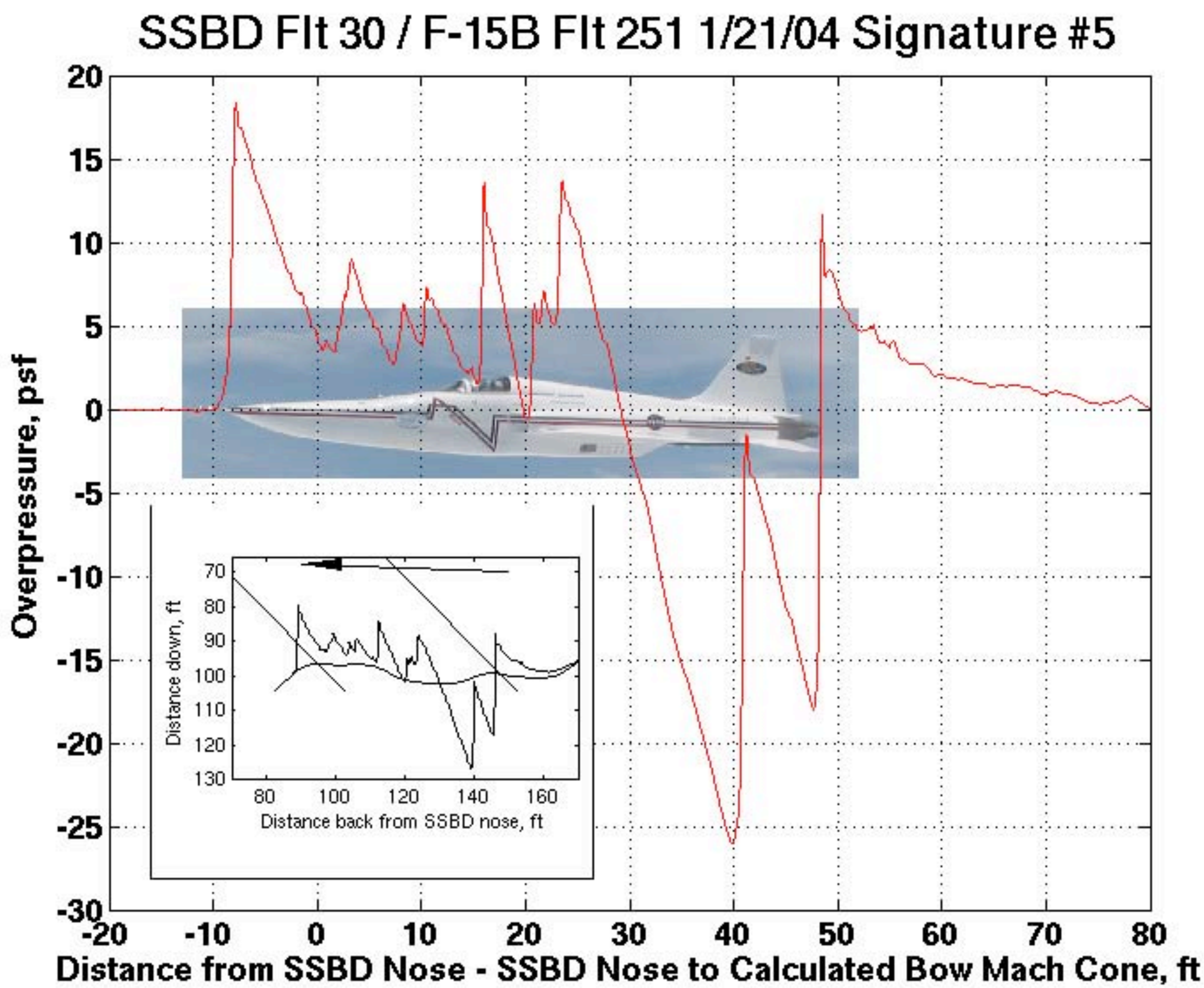
Pressure Overshoot Premonition

F-5E Shaped Sonic Boom Experiment

- **Measured pressure overshoots BEFORE shock wave, reason unknown**

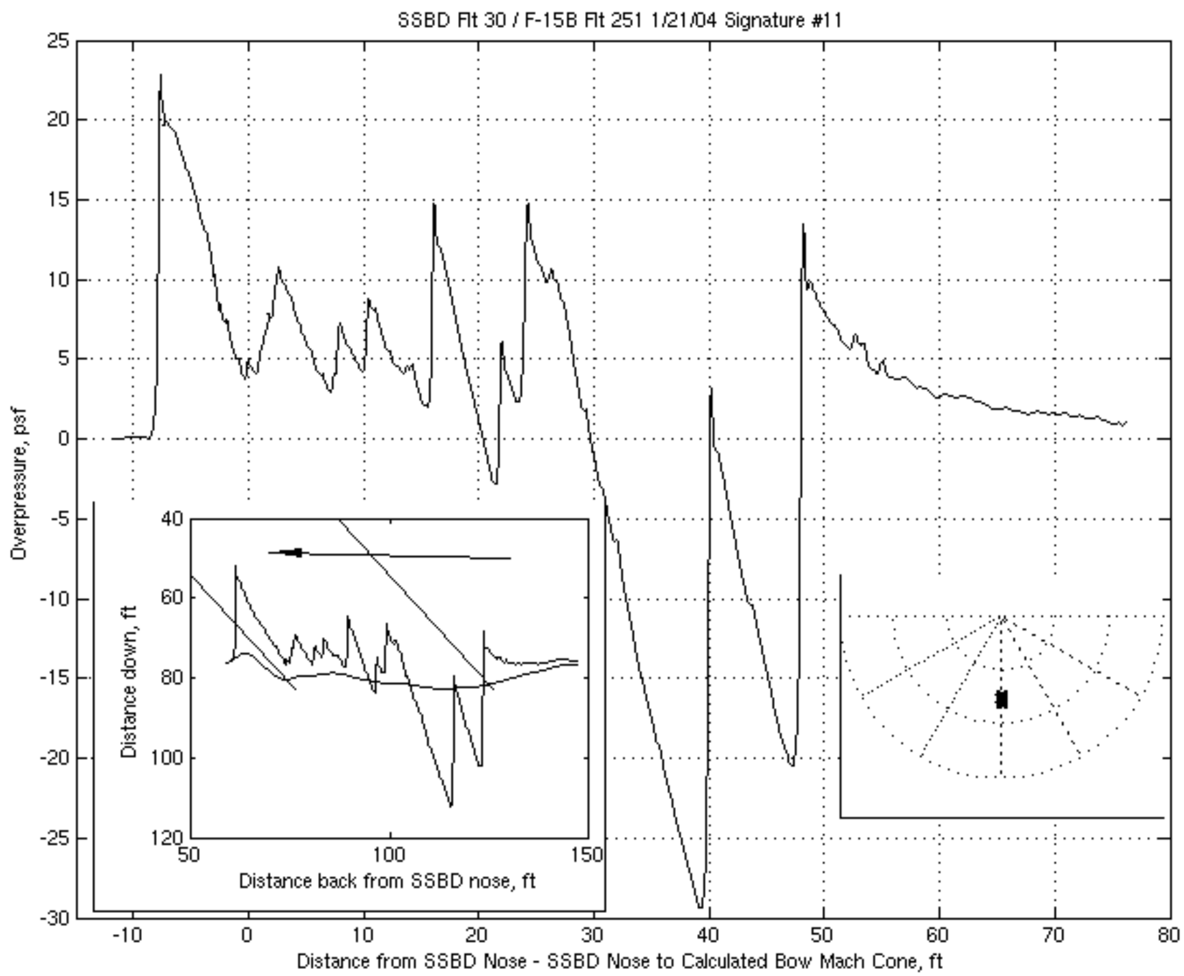


Near-Field Probing Shock Features



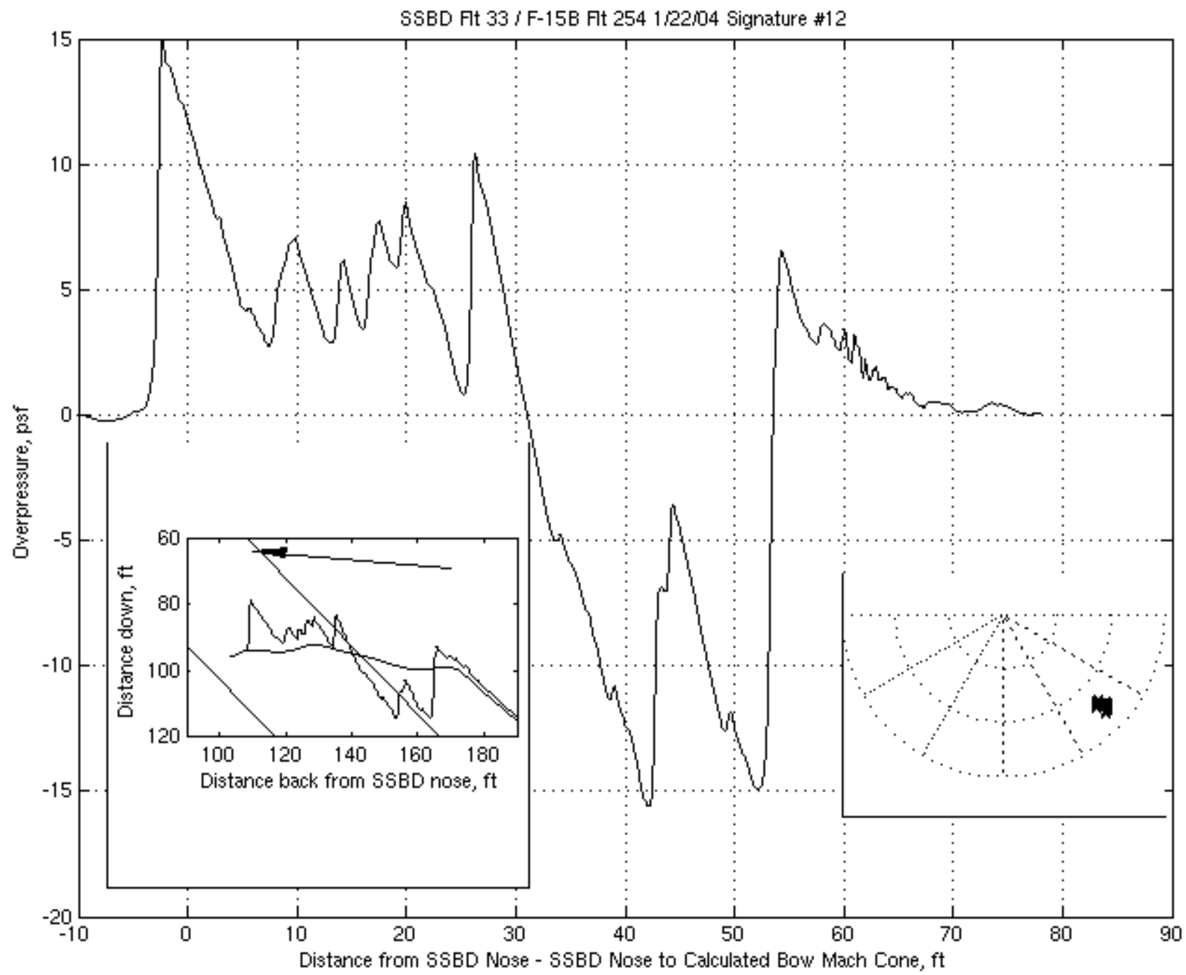
Near-Field Probing Directly Under

F-5E Shaped Sonic Boom Experiment



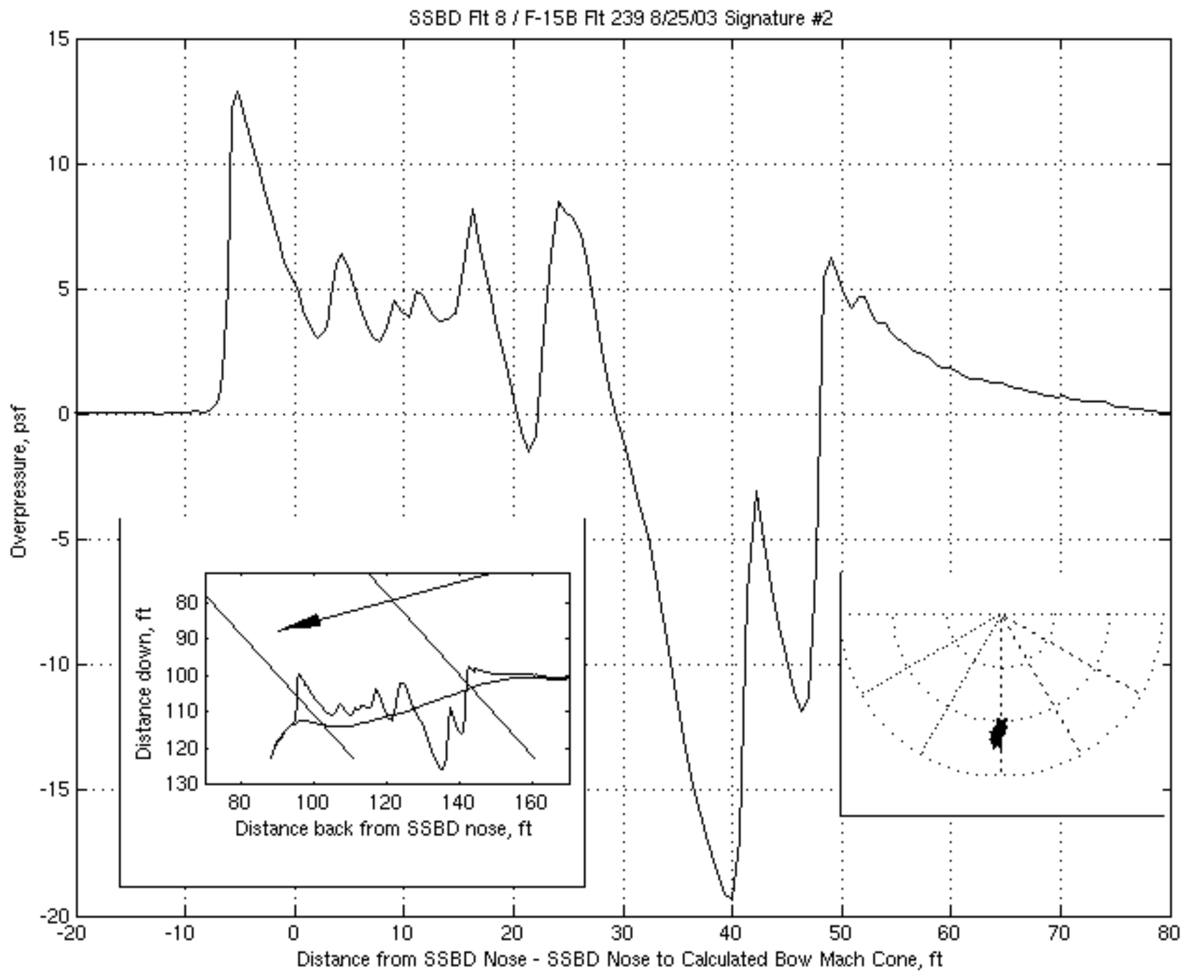
Near-Field Probing to Side

F-5E Shaped Sonic Boom Experiment



Flt 8 Signature 2

F-5E Shaped Sonic Boom Experiment



Flt 8 Signature 2 Animation

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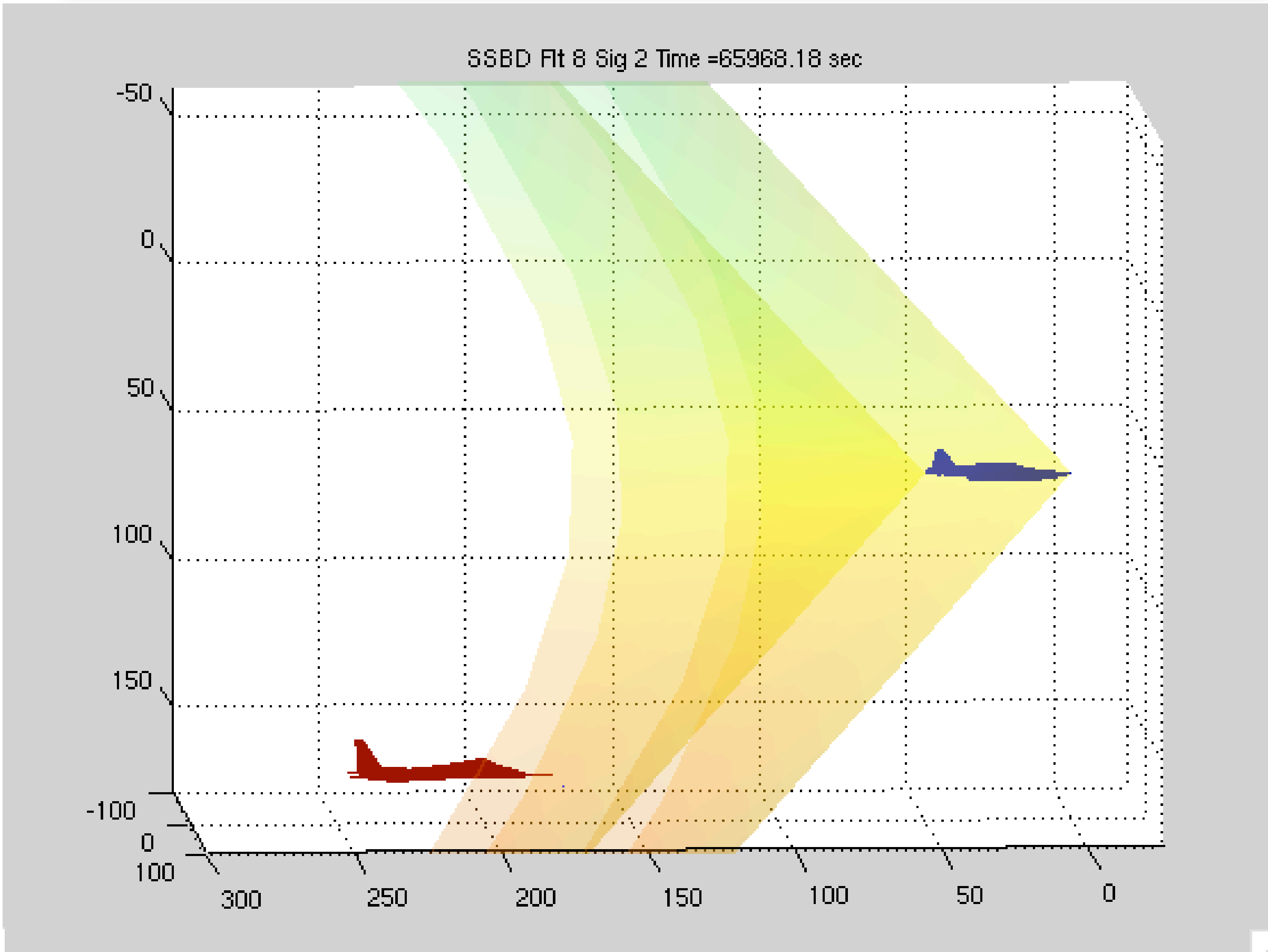

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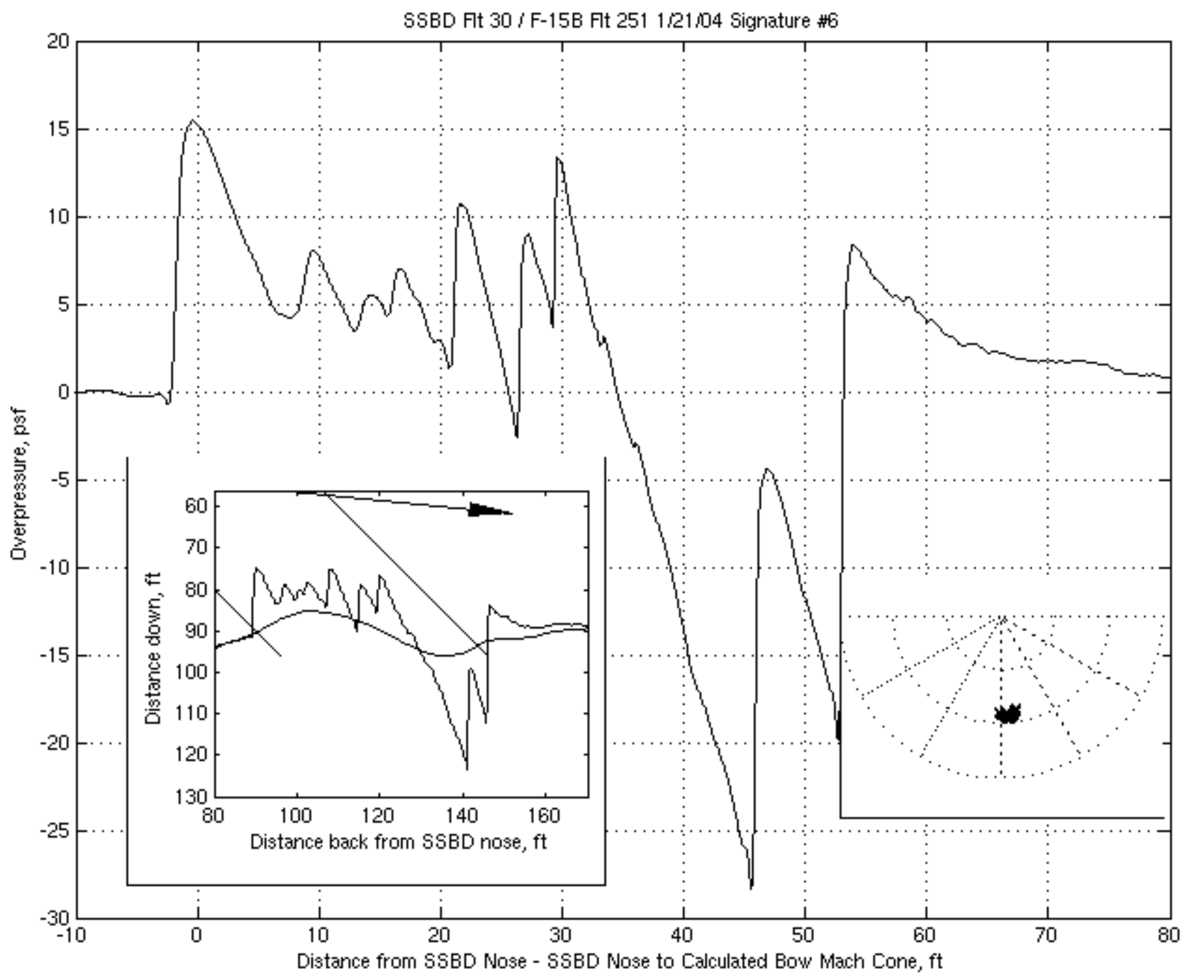
F-5E Shaped Sonic Boom Experiment



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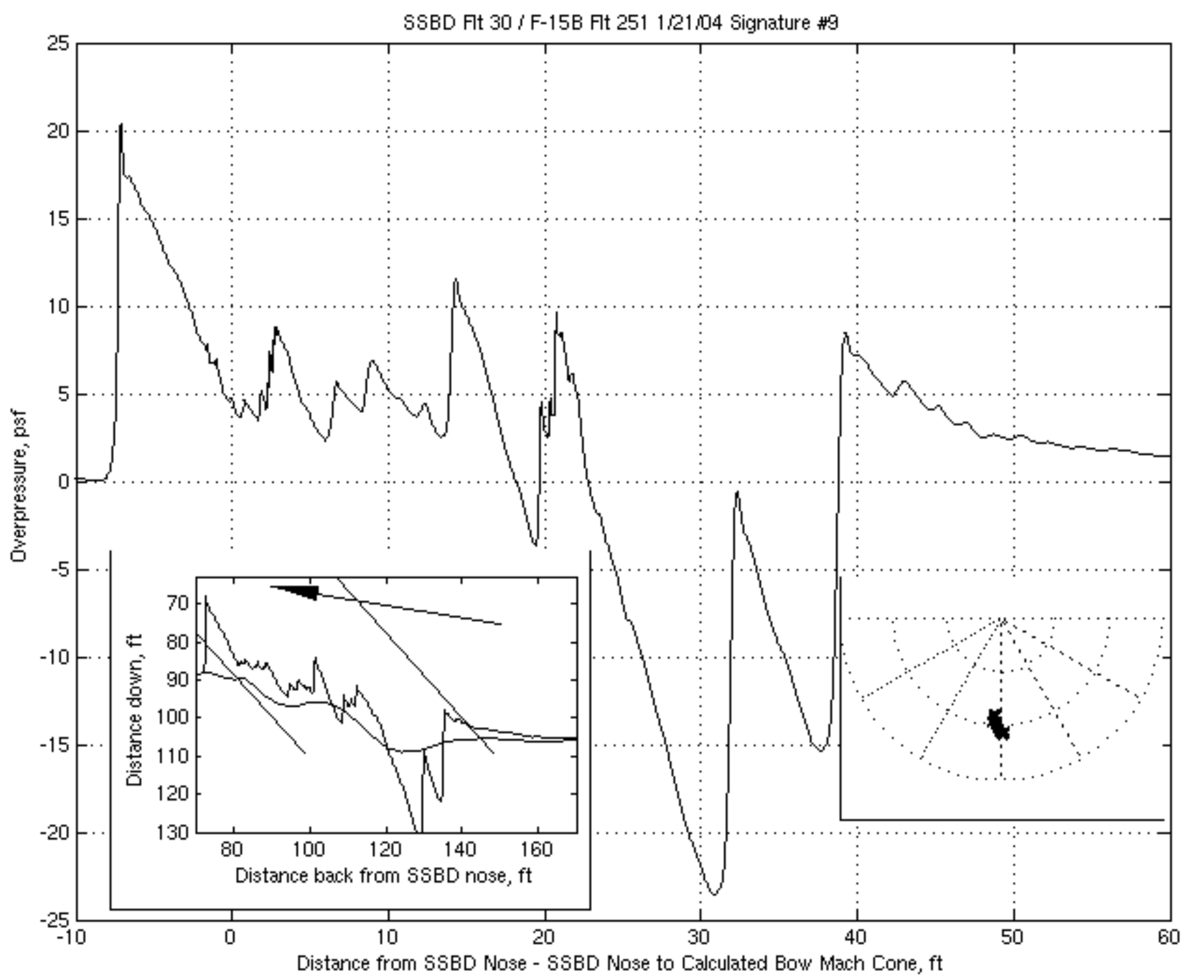
F-5E Shaped Sonic Boom Experiment



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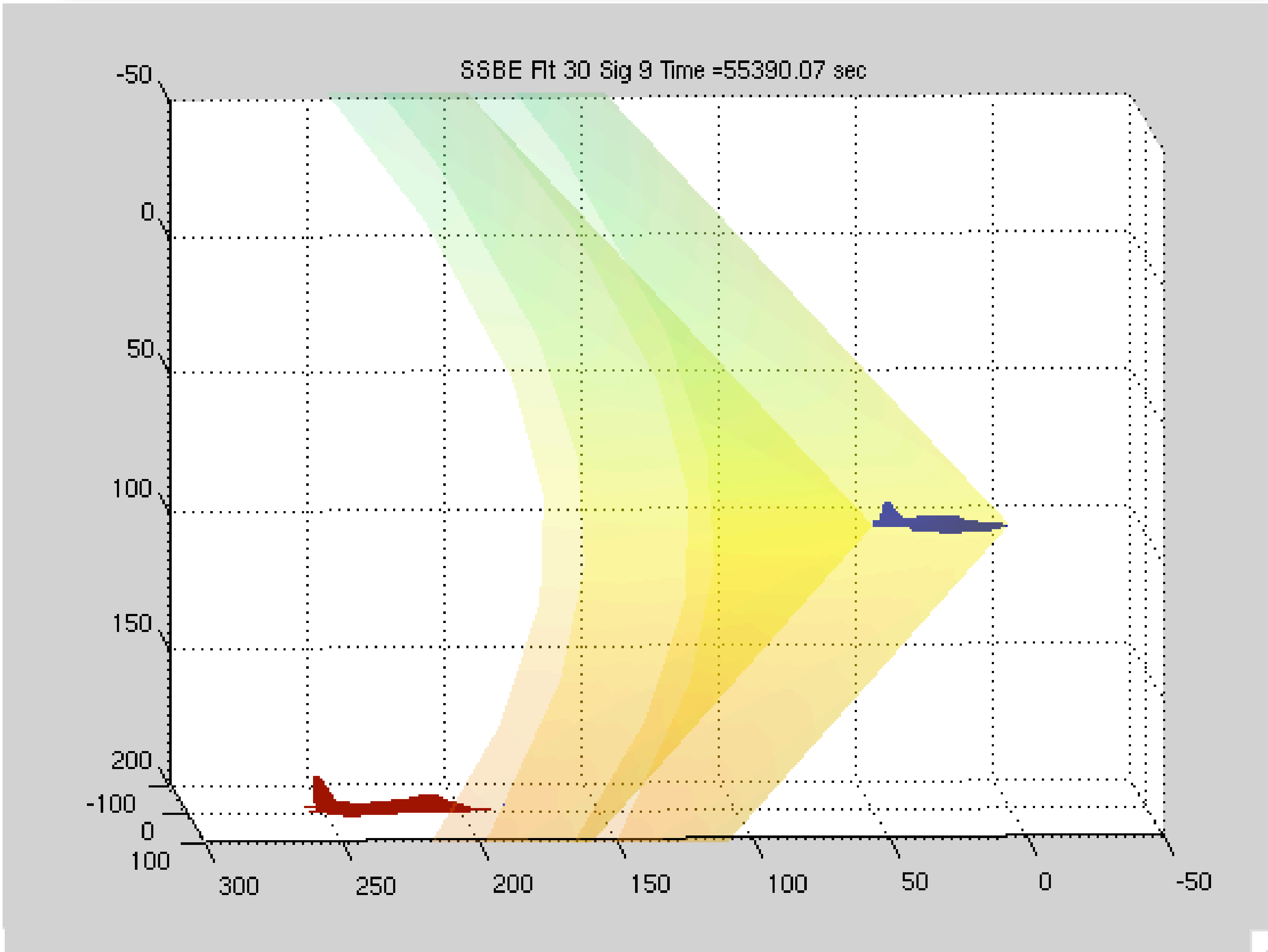

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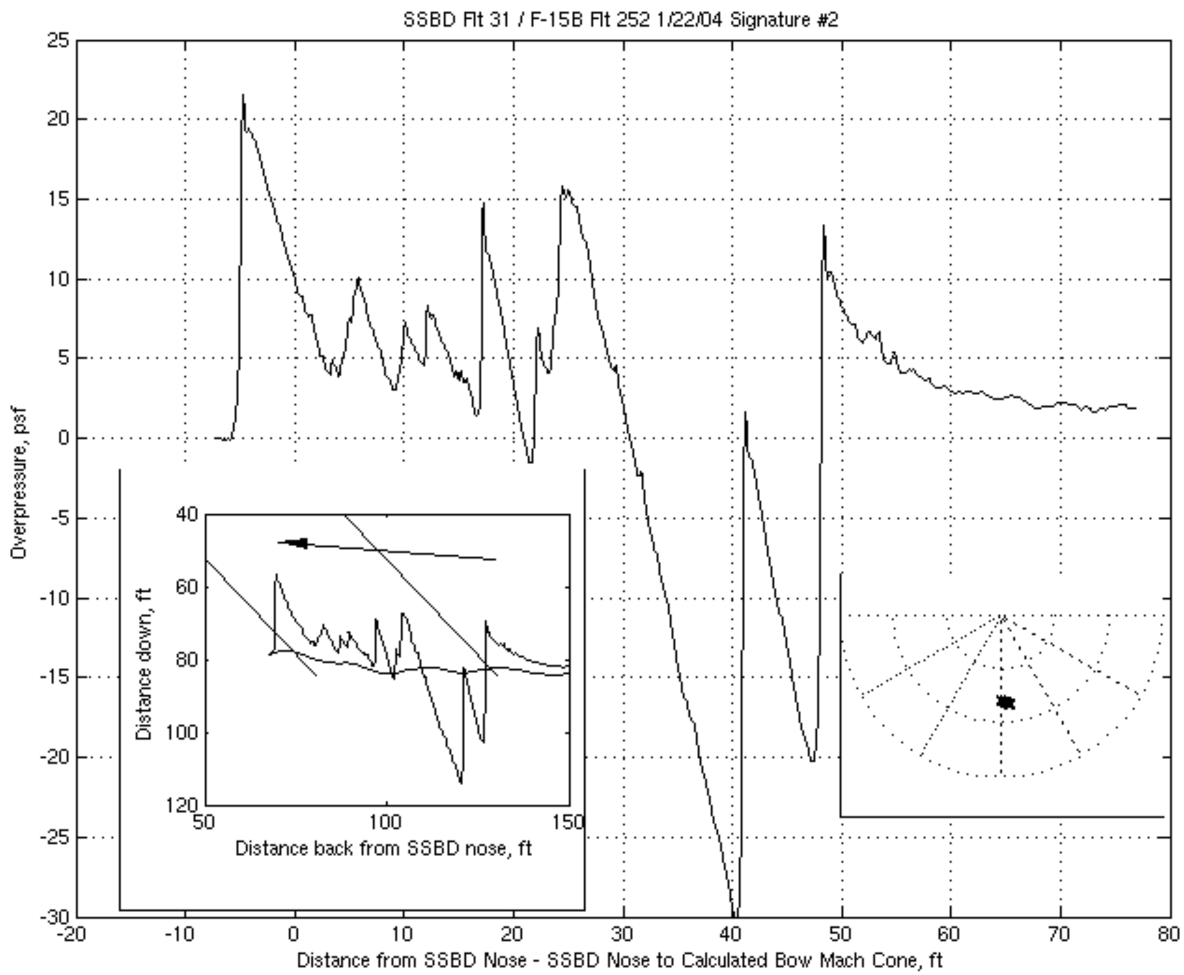
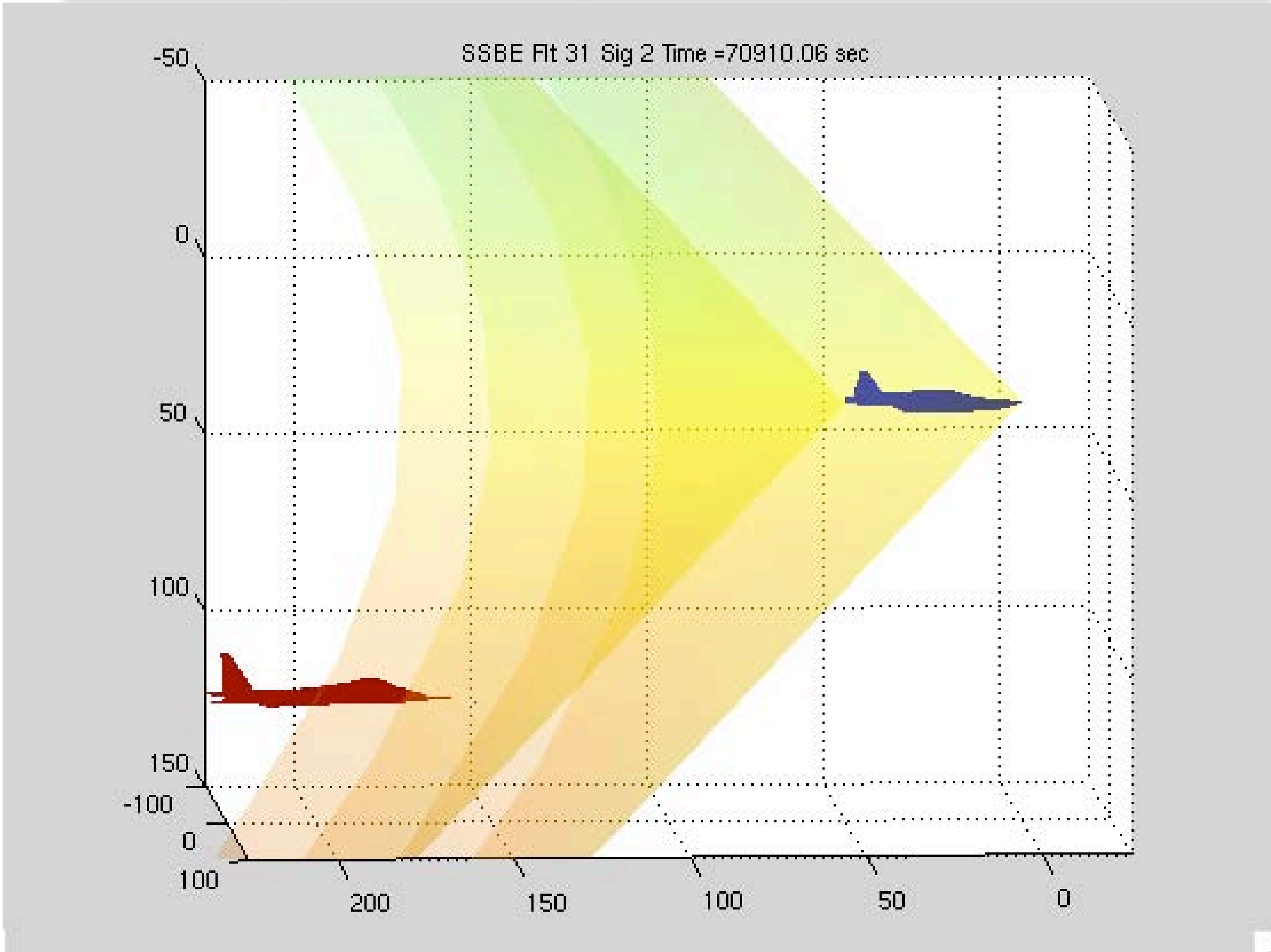
F-5E Shaped Sonic Boom Experiment



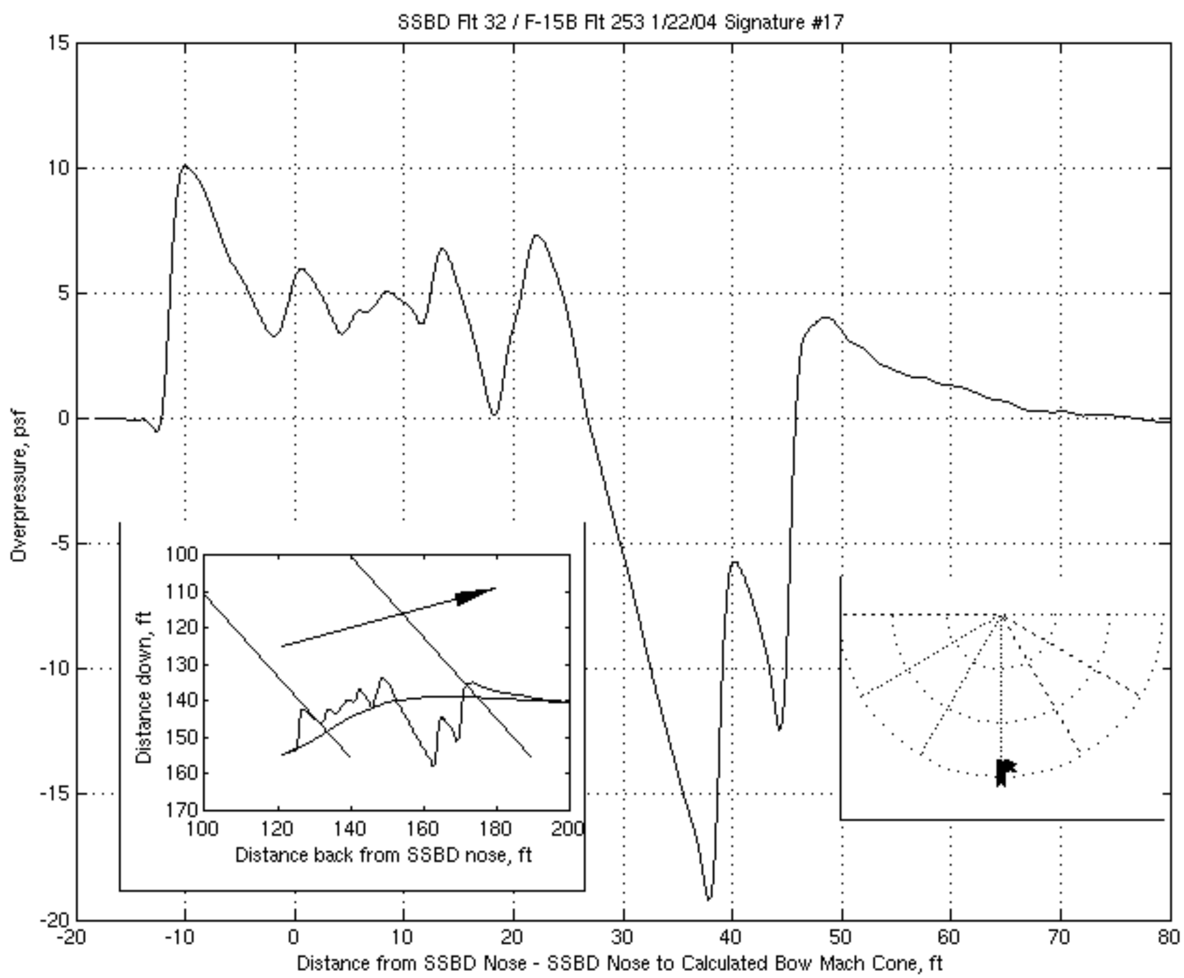
Flt 31 Signature 2 Animation

F-5E Shaped Sonic Boom Experiment



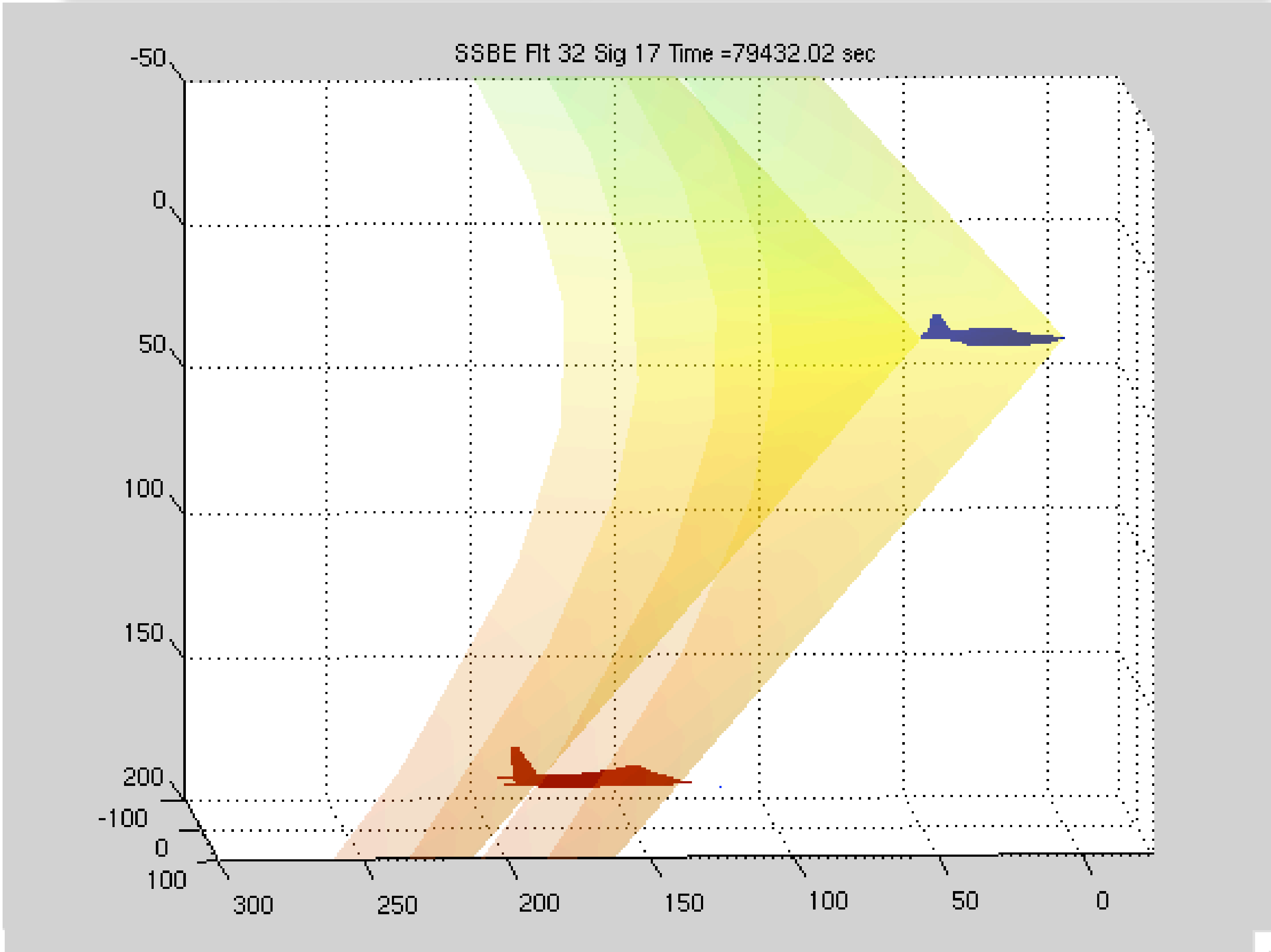
Flt 32 Signature 17

F-5E Shaped Sonic Boom Experiment



Flt 32 Signature 17 Animation

F-5E Shaped Sonic Boom Experiment



SSBD/E Airborne Data Summary

F-5E Shaped Sonic Boom Experiment

- Airborne Data Gathered
  - SSBD Airdata, GPS, Inertial package on 28 flights
  - Baseline F-5E GPS on 11 flights
  - F-15B shock pressures, GPS on 6 flights, 69 probings measured
  - L-23 glider measured pressures, GPS on 13 flights, 29 booms recorded
  - GPSsonde weather balloon data
- Ready for comparison to CFD, propagation to ground
- Further effort
  - Refine relative position data (~ several ft) using optical method from Autonomous Aerial Refueling program
  - AIAA papers at Reno, January 2005
  - Refine pneumatic lag simulation
  - Investigate “ringing” in large tank
  - Investigate pressure overshoot premonition
  - Investigate realtime GPS velocity errors on SSBD, F-5E GPS units